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RECENT URANIUM DEVELOPMENTS IN ONTARIO

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ABSTRACT

Uraniferous reef-type quartz pebble conglomerates of Lower Huronian age, north of Lake Huron, and disseminated uraninite-bearing pegmatites in the Greenville sub-province of the Canadian Shield have been under investigation in Ontario during the past two years. Very large tonnages of low-grade ores have been disclosed, particularly in the reef-type conglomerates. Owing to the fine state of division of the uranium minerals, the discovery of such deposits is dependent, in a large measure, on radiometric prospecting methods. These recent developments lead to the conclusion that increasing numbers of commercially important deposits will be found under analogous geological conditions elsewhere in eastern Canada and in corresponding Precambrian formations in the United States. The development of such deposits for production is dependent upon integrated mining and metallurgical extraction operations requiring high capital costs, and the feasibility of commercial production, in many instances, will be determined by Government purchasing policy.

INTRODUCTION

Two geologic types of uranium deposits having grade and dimensions consistent with the requirements for large-scale production have been explored and developed in Ontario during the past two years. One of the geologic types has been found in reef-like conglomerates of Huronian age in the Blind River area north of Lake Huron; and the other in pegmatitic dikes and lenticular bodies in the Grenville sub-province of the Canadian Shield in the vicinity of Bancroft in southeastern Ontario (Fig. 1). Additionally, several hundred individual uranium discoveries have been made in Precambrian formations throughout Ontario in recent years, mostly in pegmatites. With few exceptions, the greatest number of the discovered occurrences are of minor significance, or their economic worth remains to be determined. Recent developments, generally, are of interest to geologists in the United States as analogous geologic conditions for the occurrence of uranium prevail in the Proterozoic formations of the Lake Superior region, the extension of the Grenville sub-province into the Adirondack district, and in the pegmatite-

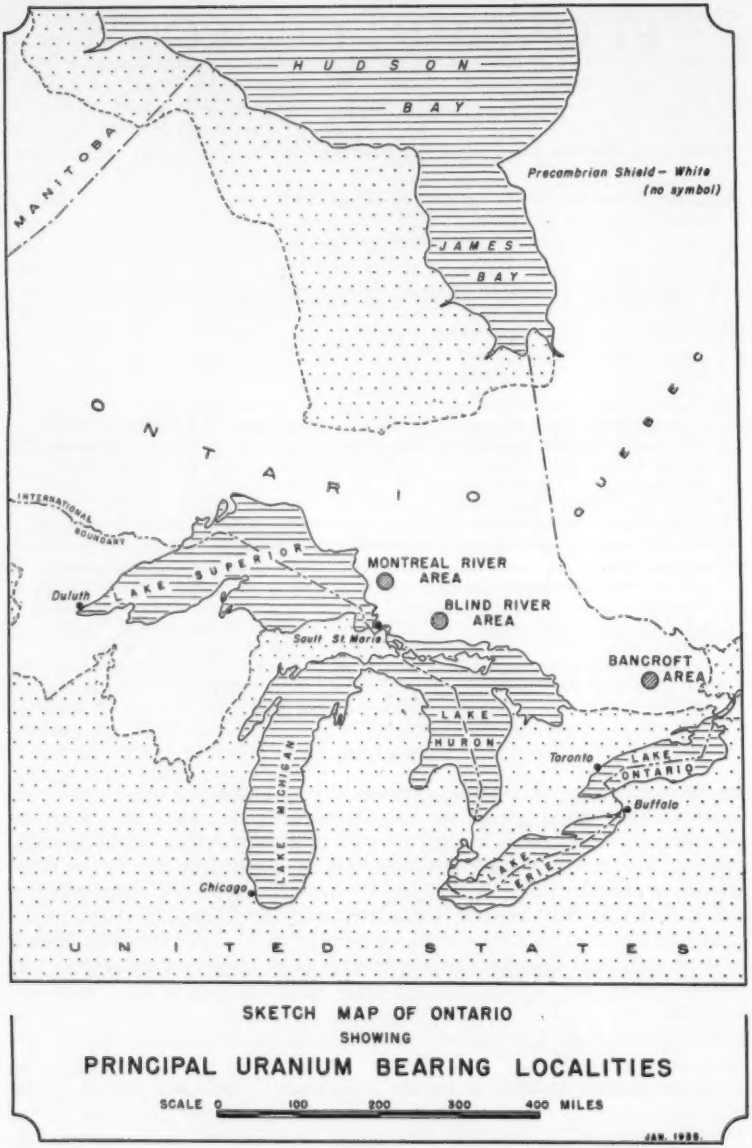
HUDSON
BAY
MANITOBA
Precambrian Shield – White
(no symbol)
JAMES
BAY
ONTARIO
QUEBEC
INTERNATIONAL
BOUNDARY
LAKE SUPERIOR
Duluth
MONTREAL RIVER
AREA
BLIND RIVER
AREA
Sault St. Marie
BANCROFT
AREA
LAKE
HURON
Toronto
LAKE
ONTARIO
Buffalo
LAKE
MICHIGAN
Chicago
LAKE
ERIE
UNITED STATES
SKETCH MAP OF ONTARIO
SHOWING
PRINCIPAL URANIUM BEARING LOCALITIES
SCALE 0 100 200 300 400 MILES
JAN. 1955.

FIG. 1.

bearing areas of the eastern United States. In view of the discoveries made in Ontario, it is a reasonable prediction that similar occurrences will be found in the United States in increasing numbers. In the largest deposits disclosed to date in Ontario, the principal uranium-bearing minerals, pitchblende, uraninite, and brannerite, are in a fine state of division and are rarely megascopically visible. The discovery of such deposits is, therefore, largely determined by the use of radiometric prospecting methods; and the accelerating rate of discovery in Ontario during the past few years is a direct reflection of the increased use of the geiger and scintillation counter.

HISTORICAL SUMMARY

The first report of a uranium mineral in Ontario was by Dr. J. L. LeConte in 1847 (9) with reference to a locality on the shore of Lake Superior, some 70 miles north of Sault Ste Marie. The probable locality was "re-discovered" near the mouth of Montreal River in 1948 by prospector Robert Campbell (8), initiating considerable exploration of the area which resulted in a number of additional discoveries. However, no commercial deposits resulted from this period of exploration.

Secondary uranium minerals were reported in fractures and cavities of magnetic iron ores at the old Victoria mine, Haliburton County, in 1874 (10) and from the Seymour iron ore bed in Hastings County in 1887 (11).

In 1914, when Sir S. Brunton investigated the occurrence of radioactive minerals in Ontario, only two additional localities were listed, namely, Raglan-Carlow townships in Hastings County, and Lyndoch township in Renfrew County (12). By 1932 the number of radioactive occurrences reported in Ontario remained at less than 30, and with the exception of the three occurrences reported in the previous century, all were associated with pegmatites in the Grenville sub-province of the Shield between Georgian Bay and the Ottawa River (5). As a result of prospecting activities since 1948 more than 180 uranium-bearing occurrences and localities in Ontario are listed by Lang (8) up to 1951. Since 1952, that number has now grown to several hundred, and the first promising prospects for commercial production are in the course of being developed.

Throughout the period from 1922 to 1952 repeated attempts had been made to develop pegmatitic radioactive fluorite-bearing deposits near Wilberforce in Haliburton County, and in at least one instance, a concentrator had been erected; but no commercial production of uranium was achieved.

Late in 1943 the acquisition and development of new uranium discoveries in the Northwest Territories, Yukon and several of the provinces were reserved to the Crown, and exploration was restricted to Government agencies. During the following four years prospecting for uranium was closed to the large body of professionally trained prospectors in Canada, but towards the end of 1947 the restrictions were removed. The accelerating rate of new discovery since that date is a direct reflection of this action. This period of exploration resulted in the disclosure of large tonnage pegmatitic deposits in southeastern Ontario, and culminated in the discovery of extensive deposits of low to moderate grade ores in the basal Huronian formations north of Lake

Huron during 1953–4 (6). Two of the most important localities in Ontario are described in the following pages.

HALIBURTON-BANCROFT AREA, SOUTHEASTERN ONTARIO

Geological Summary.—The Haliburton-Bancroft area was the subject of a classical description by Adams and Barlow (2) of Grenville sub-province geology (Fig. 2). In this district the Grenville series of crystalline limestone, quartzite, and paragneisses is well developed stratigraphically, the beds having been subjected to complex folding and relatively intense regional metamorphism, giving rise to a variety of gneisses and limestone derivatives. The paragneisses include biotite, amphibole, pyroxene, garnet, and sillimanite-bearing types in addition to the more common feldspathic gneisses.

The sedimentary strata have been involved in both open and isoclinal folding, and intruded by bodies of granite, diorite, and gabbro, many of which are now gneissoid. Amphibolite, scapolite, pyroxene, and nepheline-bearing rocks have been developed by action of the intrusions on the limestones and, altogether, an unusually complex mineral assemblage is present throughout the district. Apatite, corundum, feldspar, fluorite, garnet, gold, graphite, iron ores, mica, molybdenite, nepheline syenite, and pyrite have been mined in the district, and many of these minerals occur in pegmatitic deposits.

Pegmatites.—Pegmatite, occurring as sills, dikes, sheets, and irregular masses, is prevalent throughout the district, cutting granitic and basic intrusions as well as the metasedimentary Grenville formations. Ellsworth (5, p. 196–199) has distinguished four general types of pegmatites in the district, as follows:

(1) Ordinary granite pegmatite, ranging from graphic granite to coarsely crystalline textures. These bodies contain a variety of accessory minerals, including the rare earths, uranium and thorium-bearing minerals; and and several such dikes have been mined for feldspar.
(2) Syenite pegmatites, commonly quartz deficient and containing corundum.
(3) Nepheline-soda feldspar pegmatites with accessory calcite.
(4) Calcite-fluorite-apatite pegmatites, occurring as "vein dikes" and comcommonly containing uranium and thorium-bearing minerals.

Until recently, most occcurrences of radioactive minerals in southeastern Ontario were found in ordinary granite pegmatites that had achieved a high degree of segregation into relatively large and pure masses of quartz, feldspar, and mica; but in which the rare-element minerals were erratically distributed. The writer has often referred to this type of occurrence as "plum-in-a-pudding" deposits, and, invariably, the "plums" are too few or too widely spaced to encourage prospects of commercial production.

More recently, a new type of pegmatitic deposit has been recognized as the disseminated uraninite-bearing pegmatites. These range in composition from granite to syenite; but unlike the ordinary granite pegmatites, they commonly exhibit neither graphic fabrics nor large segregations of quartz or feldspar.

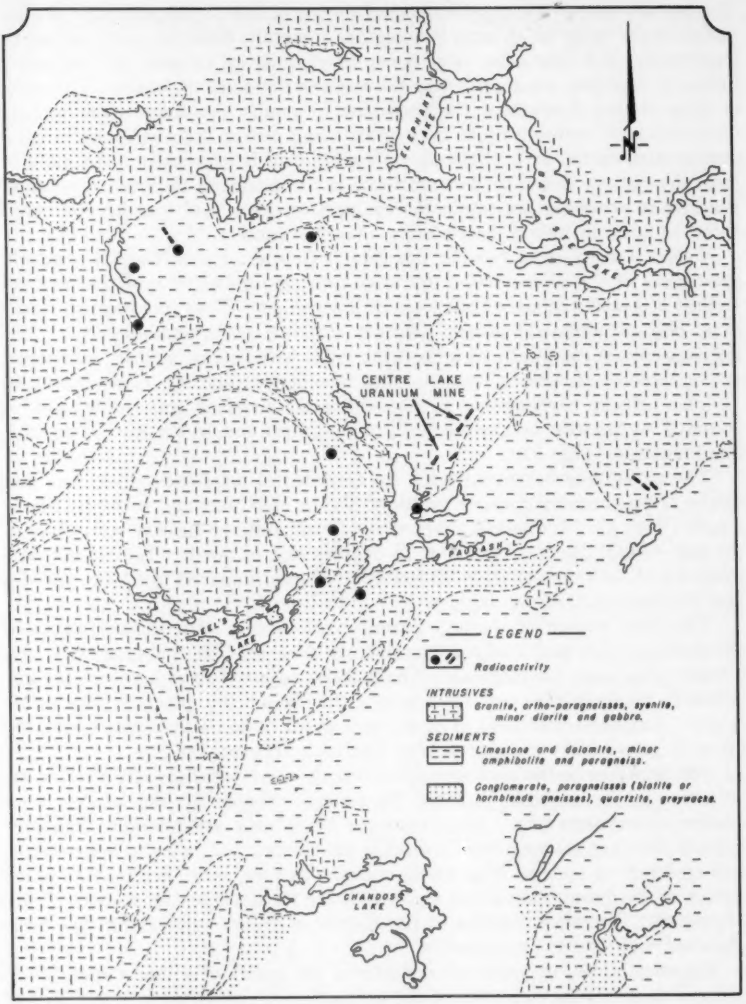
CENTRE LAKE
URANIUM MINE
ELEPHANT LAKE
PATTERSON
DEER LAKE
CHANDOS LAKE
LEGEND
Radioactivity
INTRUSIVES
Granite, ortho-paragneisses, syenite, minor diorite and gabbro.
SEDIMENTS
Limestone and dolomite, minor amphibolite and paragneiss.
Conglomerate, paragneisses (biotite or hornblende gneisses), quartzite, greywacke.
GEOLOGICAL SKETCH MAP
OF THE
BANCROFT AREA SHOWING RADIOACTIVE ZONES
SCALE 0 1 2 3 4 5 MILES
JAN. 1955.

FIG. 2.

The texture may be even granular, and the grain size of the feldspars is commonly in the order of ¼ inch. Accessory minerals, however, such as biotite, hornblende, and pyroxene, may occur in crystals or clusters up to several inches in diameter, commonly near the walls of the dikes or lenses. Uraninite is disseminated throughout the pegmatite in grains less than 1 mm in long dimension, and concentrations may occur along one or both walls, or in association with biotite or hornblende. Uranothorite is erratically distributed in most deposits of this type, but uraninite is the principal radioactive mineral. Fluorite is generally present in the radioactive dikes, and sparingly disseminated sulfides, including molybdenite, may be found.

Centre Lake Deposits.—The deposits at Centre Lake in Cardiff township are typical of the disseminated uraninite-bearing pegmatitic type and are described in greater detail for purposes of illustration. Here, the deposits occur in a belt of metasedimentary gneisses striking north-northeasterly. The gneisses consist essentially of feldspathic types with biotite, garnet, sillimanite, and amphibole variations, some of the members exhibiting augen textures.

The belt of paragneisses is approximately one-half mile wide, and is bounded on the west by granite and granite-gneiss and on the east by crystalline limestone (Fig. 3).

The paragneiss belt is intruded by a swarm of pegmatitic dikes and lenticular bodies occurring over a width of 500 to 1,000 feet and several miles in length (Fig. 3). Individual dikes strike north, but are successively offset to the east so that the trend is about 15 degrees east of north. Individually the dikes are in the range of 10 to 30 feet wide, several hundred feet long, and dip east at approximately 50 degrees.

The dikes consist of coarsely granular red syenite with concentrations of pyroxene crystals and clusters in a narrow zone near the hanging wall, and a wider zone near the footwall. These zones adjacent to either wall are enriched in uranium, the central portions of the dikes being generally less radioactive. Further enrichment in uranium is noted in many instances where the dikes become narrower, approaching lenticular terminations.

The lithology of the enclosing formations is considered to have exerted an influence on the mineralogy of the dikes and, consequently, on the degree of uranium enrichment (7). As an example, hornblende and pyroxene-rich portions of the dikes are associated with dike intersections of lime and magnesium-rich members of the enclosing paragneisses. In turn, there is a marked association of the distribution of uraninite with the ferromagnesium content of the pegmatites. In other deposits in the district a similar relationship has been observed with biotite or magnetite.

Genetically, the deposits are considered the result of a late magmatic or deuteric stage in the evolution of the pegmatites. Calcite is prevalent in the wallrocks, and primary calcite has been recognized in many dikes throughout the district. This mineral doubtless assisted metasomatic precipitation of fluorite from fluorine-bearing solutions with which uraninite is commonly associated. Furthermore, the relationship of radioactive material with fractures or with sparing amounts of chalcopyrite and molybdenite supports the concept that the uranium is not a primary constituent of the pegmatites, but has been introduced relatively late in the magmatic sequence.

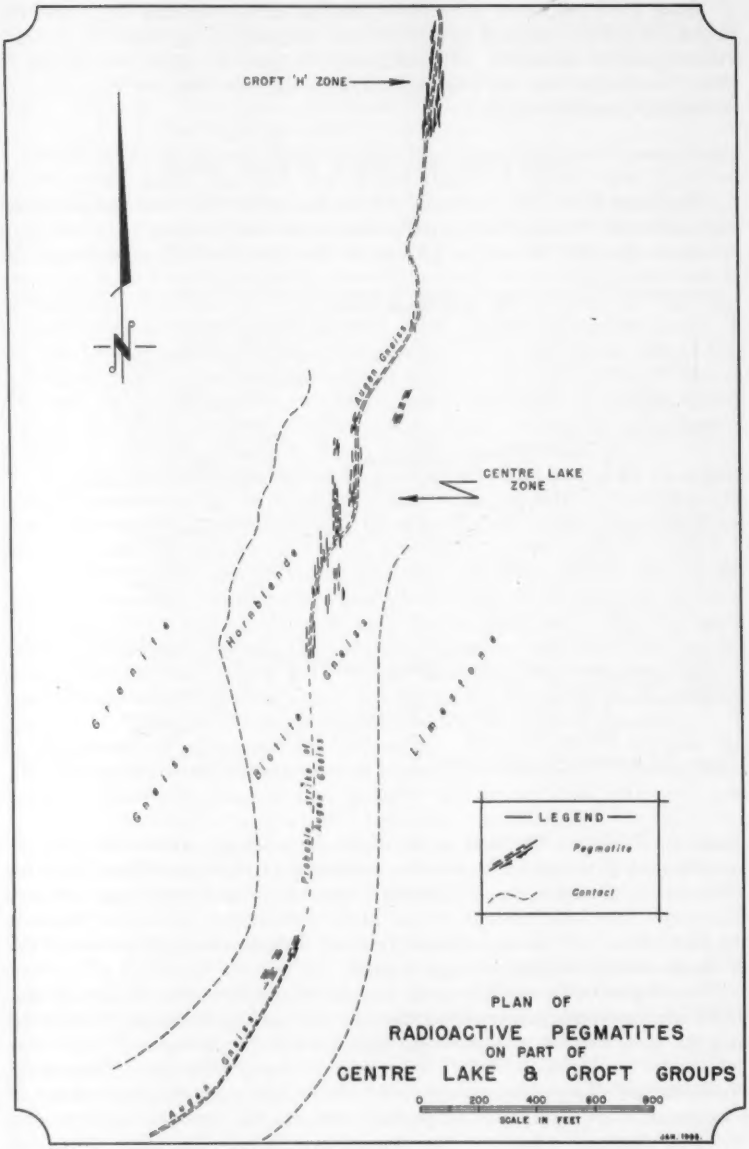
CROFT 'H' ZONE
CENTRE LAKE ZONE
Granite
Gneiss
Hornblende
Gneiss
Biotite
Gneiss
Limestone
LEGEND
Pegmatite
Contact
PLAN OF
RADIOACTIVE PEGMATITES
ON PART OF
CENTRE LAKE & CROFT GROUPS
0 200 400 600 800
SCALE IN FEET

FIG. 3.

Since 1953 a number of uraninite-bearing occurrences has been observed in the district in bodies of pyroxenite and scapolite along contacts of Grenville crystalline limestone with paragneiss or granitic intrusions. None of these occurrences has yet been studied in detail, but they are essentially of contact-metamorphic origin.

BLIND RIVER AREA NORTH OF LAKE HURON

The Blind River area is situated within the belt of Huronian sedimentation north of Lake Huron, which structurally is part of the great Penokean geosyncline. In 1948 the writer (3) noted that the Proterozoic basins of the

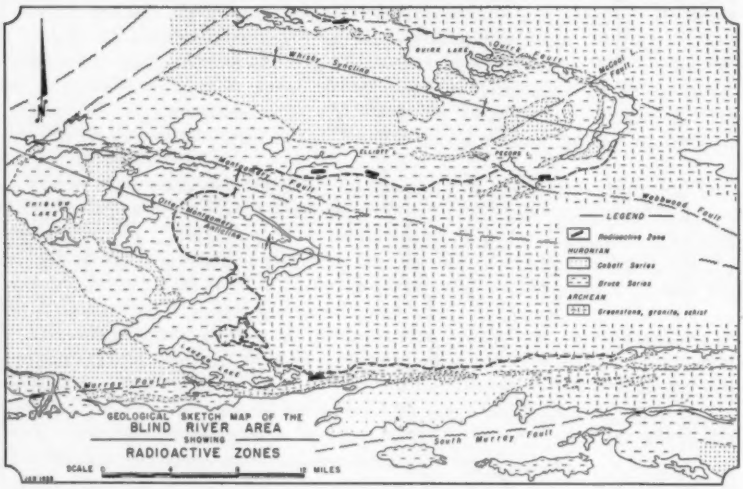

FIG. 4.

Canadian Shield, on the basis of metallogenetic analogy, offered the most favorable geological conditions for the occurrence of either pitchblende-bearing veins or uranium-bearing sedimentary deposits. Since that time uranium discoveries have been made in several of the Proterozoic basins; and those in the Blind River area have attracted the most widespread attention as a result of the disclosure of large tonnage deposits.

The Huronian formations north of Lake Huron were the subject of some of the earliest investigations undertaken by the Geological Survey of Canada; and the most recently published geological studies on a regional scale were done under the direction of Collins between 1914 and 1924 (4). Essentially, Huronian sedimentary formations rest with marked angular unconformity on a basement of crystalline schists, gneisses, and granitic intrusions representing the older Archean complex. The Huronian sediments, consisting largely of

quartzites with conglomerates, grits, arkose, argillite, and shale, are generally disposed in structural basins resulting from relatively open folds (Fig. 4); although in parts of the Lake Huron district the folding is locally complex and the formations assume metamorphic characteristics analogous to the crystalline basement. Widespread intrusions of late Precambrian diabase and gabbro postdate the Huronian folding.

In the Blind River area the lowermost Huronian formation is prevailingly a "sea green" dense quartzite, with minor argillite members, that is several hundred feet thick. In earlier studies this has been referred to the Mississagi quartzite (4), but there is some question of stratigraphic correlation throughout the region. Within the quartzite are one or more conglomerate lenses, generally from 4 to 16 feet thick, several thousand feet in length, and which, in many instances, have been traced down-dip from the outcrops by drill holes for a distance of several thousand feet. Most of the conglomerate lenses in the quartzite lie within a stratigraphic distance of 200 feet of the base of this formation, and one conglomerate member is commonly within 5 to 20 feet of the base. The conglomerate consists of egg-shaped white to reddish quartz pebbles and cherty textured pebbles closely packed in a matrix of quartzite, feldspathic quartzite, or arkose that is extensively sericitized.

The principal uranium deposits in the district are restricted to the quartz conglomerate lenses in the lower-most Huronian quartzite formation. The descriptive and economic geology of the deposits has recently been discussed by Joubin (6).

Structurally, the base of the Huronian in the Blind Rivers area is expressed as a large reversed "S"-shaped fold representing a gently westerly pitching anticline between the south and central limbs, and a synclinal basin between the central and north limbs. The Huronian formations truncate the underlying isoclinally folded and steeply dipping Archean complex. Late or post-Huronian faulting along a west and northwesterly system of ruptures has resulted in dislocations of the Huronian and pre-Huronian formations.

Radioactive Conglomerates.—Radioactive conglomerates at or near the base of the Huronian have been determined at a number of localities from surface exposure or diamond drilling over a distance of about 100 miles, representing the surface trace of the Huronian unconformity. In overlying Huronian formations in the north sector of the Blind River area are horizons of small pebble and "pea" conglomerates as well as lenses of hematite ore and chalcopyrite-bearing differentiates of diabase, carrying both uranium and thorium.

Following the discovery of the uranium-bearing conglomerates near the base of the Huronian, the analogy to the quartz-pebble gold reefs of the Witwatersrand was immediately recognized by geologists, and the prospects of extensive "payability" of reef-type deposits accelerated exploration and development. This analogy is striking with respect to the similarity of the size, shape, and distribution of quartz pebbles, gold content (which at Blind River is sparing and erratic), and pyrite content of the conglomerate matrix.

In the ore-bearing conglomerate lenses the arenaceous matrix between the pebbles is extensively sericitized and may contain up to 10 percent or more

pyrite. The uranium is present in discrete mineral particles distributed through the matrix. The principal ore minerals are said to be brannerite and pitchblende (6); and are rarely seen with the naked eye.

A typical cross-section through one of the deposits is shown in Figure 5. The surface geology of this part of the south limb of the structure has been described by Abraham (1). Here the Huronian formations unconformably overlie Archean granite-gneiss and porphyry. The basal ore-bearing conglomerate does not necessarily rest directly on the erosion surface, but is commonly separated by up to 10 feet of grit. The footwall is generally sharp and the hanging wall gradational. A thin lens of radioactive conglomerate overlies the ore-bearing bed in many places.

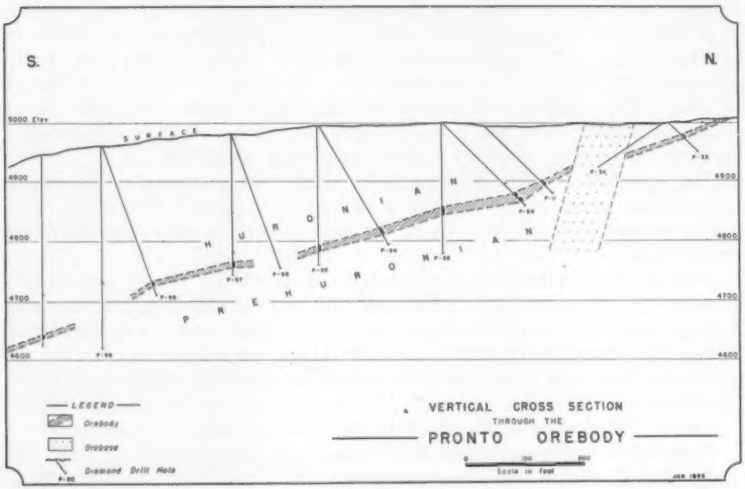

FIG. 5.

Origin of the Uranium Deposits.—The writer is inclined to view the uranium mineralization in the conglomerates as epigenetic, although many geologists are prepared to support a syngenetic origin. Adequate investigations have not yet been undertaken to support a diagnostic case for either origin. Proponents of syngenetic uranium are prepared to cite the persistent uranium content in conglomerate lenses distributed over many miles. On the other hand, the fact that, throughout a large area, weathering was sufficiently rigorous that only quartz pebbles remained above a basement of highly diversified lithology, the contemporaneous survival of indigenous uranium minerals and pyrite would require very special conditions.

Although the association of placer ores with conglomerates is an almost irresistible thought, it must also be recognized that, at one stage in their evolu-

tion, the conglomerate lenses were likely beds of high permeability; and the presence of a sericitized matrix liberally mineralized with pyrite is suggestive of hydrothermal activity.

Conclusions.—The disclosure within less than three years of two hitherto unrecognized geologic types of uranium deposits in Ontario leads to the conclusion that similar deposits will be found where analogous geologic conditions prevail elsewhere in Canada, and also in the eastern United States. Furthermore it can be expected that still other geological associations of uranium will be found as investigations are broadened. For example, the replacement deposits in crystalline limestone of Grenville age, including uranium, thorium, columbium, and rare-earths, and the association of uranium with pyrochlore, magnetite, and apatite in large disseminated deposits, offer the ultimate prospect of other sources of primary and by-product uranium production. Such deposits are being vigorously explored in Ontario and Quebec today.

The uranium content of most of the deposits in Ontario currently being developed ranges between 1.6 and 2.6 pounds per ton, and is appreciably less than the average grade of ores being mined elsewhere in North America today. For this reason individual operations of less than 500 tons per day are rarely contemplated, and production plans of 1,000 or more tons per day are favored. Thus, in order to be economically feasible, a mining operation should be based on ore reserves exceeding one million tons.

In the case of most of the deposits currently under investigation satisfactory uranium recovery cannot be achieved by mechanical concentration of the uranium minerals, and extraction methods are based on total leaching of the raw ore. Ores of the tenor being developed cannot economically withstand haulage charges to central treatment plants; and exploitation of the deposits is predicated on completely integrated mining and metallurgical extraction operations.

For these reasons high capital costs, amounting to $5,000,000 and more, are required to bring a deposit to the production stage; and such financing is only available under conditions of a long term Government purchasing policy at a unit price satisfactory to the producer.

In Ontario, uranium deposits now under development are capable of adding substantially to Canada's present production; and future developments will be based as much on Government purchasing policy as on new discoveries.

TORONTO, CANADA,
February 24, 1955

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GEOLOGY AND IRON ORES OF STEEP ROCK LAKE

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ABSTRACT

Mining operations at Steep Rock Lake since 1945 have yielded about ten million tons of high-grade iron ore and have cast new light on the geology of this long-famous Precambrian area. The productive length of this most-recently discovered of the Lake Superior ranges should exceed four miles and ore intersections have been obtained at depths down to 2,000 feet below the old lake bed, implying that potential reserves must be measured in hundreds of millions of tons.

The Steeprock group lies unconformably upon a granitic complex ("Laurentian") and consists of:

5. Interbanded flows, tuffs, and sediments
4. "Ashrock" (a basic pyroclastic containing minor flows and tuffs)
3. The "orezone"
2. Limestone and dolomite (in part showing "algal" and other organic (?) structures
1. Basal conglomerate (not everywhere present)

All these formations (together with younger basic intrusives) have been steeply tilted, more or less altered, and show foliation or brecciation in appropriate rock types. Such features (plus sporadic pyritic replacement lenses along and near the hanging-wall of the "orezone," as well as recrystallization, modification, and minor migration of the iron ores) are ascribed to the activities of a post-Steeprock ("Algoman") batholith that outcrops two miles to the west. Several major faults cross the area, the largest of which has caused a strike separation of more than two miles in the Steeprock group.

The "orezone" holds all the known iron ore-bodies, is up to several hundred feet in width, shows remarkable continuity and uniformity wherever explored, and is made up of two members. The stratigraphically lower part is chiefly manganiferous waste (averaging more than 2 percent Mn) with minor iron ore, resting residually in erosional disconformity on the underlying leanly manganiferous and ferruginous limestone and dolomite. The upper part of the "orezone" carries negligible manganese and is composed chiefly of goethite with a few relatively narrow bands of cherty, sandy, and aluminous sediments. The ores show a variety of breccia, vuggy, and colloform structures. The most common type of breccia has fragments of very fine-grained goethite surrounded either by coarsely crystalline goethite or specularite or by earthy hematite. A pisolitic facies locally present along the hanging-wall of the "orezone" contains gibbsite and resembles a ferruginous bauxite.

The field relations, mineralogy, and paragenesis suggest that the ore-bodies represent sedimentary limonite of Steeprock age, brecciated by compaction and folding, with the more finely comminuted matrix recrystallized or modified by hydrothermal solutions, locally effecting migration of iron.

In the history of most mining camps, the unique and interesting features of the geology commonly do not become apparent until long after the initial discovery and early development. To some extent the reverse holds true for Steep Rock Lake. This area, which includes the most recently discovered of the Lake Superior Iron ranges, was famous geologically long before it produced any iron ore. Indeed, the Precambrian stratigraphy here was considered of sufficient interest to prompt a visit in 1913 by the Twelfth International Geological Congress, a quarter of a century prior to the first positive drill intersection of iron ore in place beneath the lake. Starting with the initial work of H. L. Smyth more than 60 years ago, geological reports on the area [1] bear such names as those of McInnes, Coleman, Lawson, Van Hise, Leith, Uglow, Tanton, Moore, Hawley, Roberts, Bartley, and Hicks, to mention some only.

With such an eminent coterie it is hardly surprising that sharply divergent views have been put forward on the stratigraphy and structure of the area and, latterly, on the origin of the Steep Rock iron ore bodies. For some of the problems, lack of evidence still prevents final solution; for others, the areas of uncertainty have been reduced by the wealth of new information revealed by recent mining operations. Over the past ten years parts of Steep Rock Lake have been drained, some of the silts and gravels have been removed, thousands of feet of drilling have been done, and certain of the ore bodies and contiguous rocks are now exposed in three dimensions in the open pits and underground workings.

Ore production at Steep Rock commenced in 1945. Up until the end of 1953 the Errington open pit ("B" orebody) has yielded about nine million tons of iron ore averaging 56.89% iron, 0.027% phosphorus, and 7.45% silica (dry analysis) from a length of about 3,000 feet and to an average depth of 300 feet. Open pit production from the Hogarth or "A" orebody began in 1953 and, in that year, amounted to 795,000 tons, having an average content of 57.57% iron, 0.029% phosphorus, and 7.29% silica (dry analysis). Underground development of "B" orebody is well-advanced (Fig. 3) and, due to the high dip, most Steep Rock ore will ultimately be won by underground methods. The iron ore reserves of the range can hardly be assessed properly until the vexed question of origin is settled. However, exploratory drilling and geological mapping have indicated that the productive length should not be less than four miles, and ore intersections obtained at depths down to 2,000 feet below the old lake bed unite in implying that the potential reserves must be measured in hundreds of millions of tons.

Despite the scale of development to date, no complete or balanced presentation concerning the ores and geology of Steep Rock Lake will be available for some years to come. We are dealing here not with a new iron mine or two but with a whole new iron range that already clearly displays some features setting it apart from other Lake Superior iron ranges. Accordingly, this paper is concerned chiefly with certain matters of immediate controversial interest such as the relation of the rocks at the base of the Steeprock group, the nature of the carbonate member and overlying orezone, and the origin of

[1] See Bibliography at end.

the iron ore bodies. It is based on four field seasons' areal geological mapping (on a scale of one inch equals 400 feet) with more detailed studies of the exposed ore bodies, re-examination of most of the drill cores, and a study of company maps, sections, logs and reports.

ACKNOWLEDGMENTS

Grateful thanks are due to the management and technical staff of Steep Rock Iron Mines, Limited—especially to M. S. Fotheringham, President, H. M. Roberts, Consulting Geologist, and W. Samuel, Consulting Engineer—for their interest in and contributions to this investigation. Valued assistance in the field mapping was given by W. J. Huston, W. G. Wegenast, and R. Tillotson, and laboratory studies on specimens from the range were made by F. Enns (1951), G. Dann (1952), and W. G. Wegenast (1954). J. E. G. Schwellnus and P. Mott prepared the photomicrographs. Stimulating and provocative discussions with many other geologists aided in shaping the conclusions presented herein but the writer alone should be held accountable for these.

ROCK FORMATIONS

The known iron ore bodies of the area appear to lie within one member (the "orezone") of a sedimentary-volcanic assemblage known as the Steeprock group [2] (Fig. 1). A section across this group from northeast to southwest shows in succession: (1) a carbonate member (locally based by lenses of conglomerate, and grit), in contact with granitic rocks to the northeast; (2) the "orezone"; (3) a coarsely-fragmental pyroclastic known as the "ashrock" which contains one or two very basic volcanic flows; and (4) clastic and pyroclastic sediments, interbanded with flows and intrusives.

The various members of the group have been steeply tilted, display rather low-grade metamorphic effects, and show foliation or brecciation in the various rock types. Several major faults cross the area, the largest of which has caused a strike separation of more than two miles.

Granitic Rocks

The most recent general geological map [3] covering the area around Steep Rock Lake shows two large granitic areas, one to the north and east of the lake called "Laurentian" (pre-Steeprock), and the other to the northwest called "Algoman" (post-Steeprock) (Fig. 2). Only the first of these was examined during the present study, and the writer is in agreement with the findings of most previous investigators, viz., that the Steeprock group lies on this northeastern granite in erosional unconformity. The chief observations that force this conclusion are: (1) none of the rocks of the Steeprock group adjacent to the granite shows marked thermal or contact metamorphism (e.g., the carbonate member is not notably recrystallized nor has it reacted with included

[2] Formerly this was called the Steeprock *series* but, since a major disconformity occurs within it, according to Canadian Precambrian usage the term *group* is preferable.

[3] "Atikokan Area" (to accompany report by E. S. Moore, 1940).

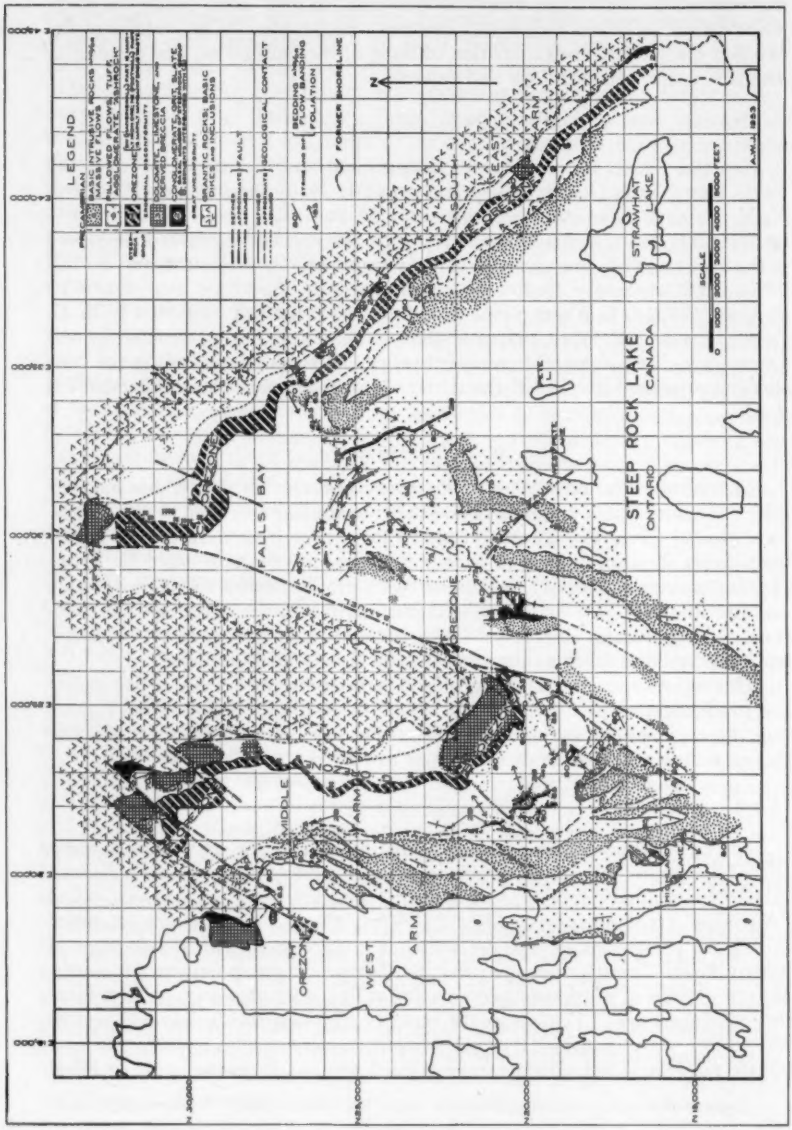

FIG. 1. Geological map of Steep Rock Lake area.

chert and clay minerals), nor have any granitic dikes been found cutting these rocks [4]; and (2) the position of the main conglomerate (2A on Fig. 1) in the sequence and the fact that this member holds many pebbles and boulders identical in lithology with rocks of the adjacent granite complex.

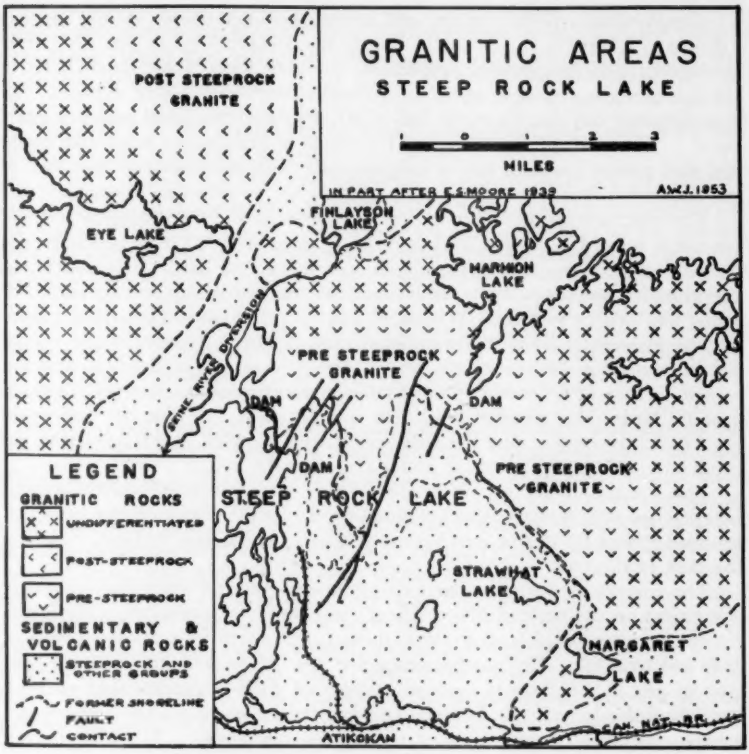

FIG. 2. Granitic areas, Steep Rock Lake.

The granitic complex north and east of the lake is made up mainly of variably gneissic granite containing numerous dark-weathering bands striking northeasterly. Some of these latter represent greenstone inclusions, and, in certain areas, their partial incorporation has produced hybrid phases in the granite. However, most such bands are quite definitely basic dikes cutting the granite and display chilled margins against it, although this feature is apt

[4] An exception is the rare, highly altered material tentatively identified as aplite, which cuts the western part of "A" orebody, which may be ascribed to the post-Steeprock "Algoman" (Fig. 4).

to be obscured by later shearing along these contacts. A few such dikes extend southwest to cut the Steeprock carbonate but most appear to be pre-Steeprock in age.

Steeprock Group

Conglomerate, Grit, Arkose, and Greywacke.—A coarse clastic member (shown as 2A in Fig. 1) forms the base of the Steeprock group but has a relatively restricted distribution, presumably marking topographic depressions in the pre-Steeprock erosion surface. Actual contacts are rarely exposed. In Conglomerate bay (at the north end of Middle Arm) the basal beds are made up of an ill-sorted rubble of angular fragments of granite and basic dike material that passes upwards into a conglomerate with well-rounded boulders of the same rock types.

The best exposure of the contact is in a tunnel across the peninsula between the north ends of West and Middle Arms. Here arkosic grit is in sharp contact with a medium-grained, basic rock regarded as one of the dikes intruding the granitic complex. The actual contact is marked by up to two inches of schist and quartz veinlets. Within 10 feet of this contact the arkose passes into conglomerate, which is continuously and perfectly exposed in the tunnel for an additional 200 feet to the west. The pebbles and boulders in this are well-rounded and are made up of about equivalent amounts of granite, hybrid granite, basic dike material, and vein quartz. The sole feature that could even remotely suggest that the adjacent granite complex is intrusive into the conglomerate is the presence of minor disseminated pyrite.

The matrix of the conglomerate is composed mostly of quartz grains. Interbanded with this are layers of small-pebble conglomerate or grit, in which rounded grains up to five mm across of quartz, chert, and feldspar make up the bulk of the rock.

The contact between the basal conglomerate-grit and overlying carbonate is exposed on the neck of Elbow Point (north of "B" orebody). Here, the carbonate is separated from granitic rocks to the north by a 30-foot width of drift and road fill. The northernmost five feet of the carbonate outcrop consists of grit in a carbonate matrix. Wegenast (1954) reports that staining tests show this latter to be dolomite and that the sub-angular clastic grains are quartz, chert, and altered feldspar up to four mm across. Towards the top of this five-foot zone are alternate one-half inch beds of carbonate and grit. Graded bedding in some grit bands suggest that the tops of these face southwest. At one point in Southeast Arm the conglomerate is separated from the overlying carbonate by impure quartzite and slaty greywacke in normal ternary succession.

Carbonate.—This member ranges from well-banded (Fig. 12) to massive, to strongly brecciated carbonate of rather contrasting chemical composition, and has been variously regarded as: (1) a sedimentary limestone or dolomite more or less replaced and veined by later ferruginous carbonate, or (2) a complete carbonate replacement of some pre-existing banded and brecciated rock.

With one exception (10), all geologists who have published reports on the area subscribe to the first alternative, although some disagreement exists as to the relative amounts of sedimentary and introduced carbonate. Thus Lawson (11, p. 14) regards the formation in part as an aggregate of fossils, and in part as calcareous detritus derived therefrom. Tanton (25, p. 3), on the other hand, states: "Stratified limestone forms less than 10 percent of the rock," but it is clear that he is referring to *all* carbonate rock within the Steeprock group (which unquestionably does include some carbonate replacements of sheared lavas and tuffs), and not just to the formation designated (3) on Figure 1.

Hicks (10, p. 10) groups the carbonate rocks (and iron ores) with the post-Steeprock batholithic intrusives.

> The replacement carbonate or the so-called footwall "limestone" is believed to be part of the end phase of the granitic intrusions. The geographic distribution of the exposed carbonate, i.e., its occurrence at the prominent bends of the granite batholith, does not suggest a sedimentary origin; and the presence of numerous inclusions of greenstone in various stages of assimilation, together with the lack of continuity to any banded structure, suggests an origin other than sedimentary. Many writers admit that there is a late carbonate replacement, chiefly iron carbonate, and having admitted the process the present writer cannot see why it should not apply to the whole mass. In the Errington "B" ore body, the iron ores are intrusive in origin, having come in as iron oxides, replacing the portion of the old shear or fault zone that was not replaced by the footwall carbonate.

Prior to the lowering of Steep Rock Lake, the carbonate was exposed in a few isolated outcrops along the northern shores. Many of these outcrops consist largely of breccia in which angular fragments of all sizes (mostly fine-grained carbonate, less commonly chert and "greenstone," very rarely pyritic material) occur within an introduced or recrystallized, relatively coarse-grained, carbonate matrix. As the lake waters receded new exposures of the carbonate were revealed (most of which show only a well-banded material) and many of these have since been linked up by diamond drilling. Accordingly, the carbonate can now be regarded as a continuous member between the underlying granitic complex (and local basal conglomerate) and the overlying "orezone." In addition, the detailed areal mapping now indicates that the carbonate breccia is most common where sharp deflections occur in the general northwesterly trend of the Steep Rock formations—at the east and west ends of Elbow Point (north of "B" orezone) and at the north ends of Falls Bay and Middle and West Arms. Thus, as many previous investigators had surmised, the breccia is the product of local deformation and the noncarbonate fragments it contains were derived from the cherty layers interbanded with the carbonate and the basic dikes that cut it; stages in the development of such breccias can be observed in the field.

The formation has a width of from 400 to 800 feet but this is notably increased in areas of folding and brecciation. A brown weathered surface is typical of the carbonate breccia and has resulted from oxidation of introduced ankeritic dolomite. Elsewhere, similar colorations may be misleading as, in some cases, they are displayed by carbonates containing negligible iron, and may represent a limonite film precipitated by the carbonate from the iron-

charged waters of the former lake. Where the carbonate was protected by varved silts, the outcrop surface is typically blue-grey.

Most exposures are of fine-grained material showing well-developed banding ranging in width from a fraction of an inch to several feet (Fig. 12 A). Minor cherty horizons stand in relief on weathered surfaces. With increasing deformation the grain size increases and the banding becomes contorted and, eventually, obliterated. Concomitant brecciation becomes more obvious along with increased introduction of carbonate, in part as a cement for the fragments, in part replacing them.

TABLE 1

Sample No.	Width (feet)	CaO	MgO	FeO	Total Fe	MnO	Total Mn	CO_2	H_2O	Loss on ignition	SiO_2	Al_2O_3	Fe_2O_3	Insol.	Total
M 43	20.0	50.78	.79	.42		.60		40.60	.29	40.89	5.80	.15	.14		99.57
44	21.0	51.8	1.7		3.0		.40			40.7	3.0				
45	9.8	53.2	1.3		1.8		.53			40.9	2.6				
49	13.0	53.0	1.2		1.9		.70			39.2	4.9				
50	8.0	53.51	.20	.45		1.02		42.44	.42	42.86	.94	.02	.11		99.11
51	3.0	57.2	1.1		1.2		.79			41.2	0.8				
52	20.5	58.0	0.2		1.0		.74			40.3	1.8				
53	21.0	52.38	.52	.35		.43		41.76	.15	41.91	4.08	.09	.11		99.87
54	23.5	57.5	0.2		1.9		.38			40.0	2.9				
55	8.0	58.0	0.2		1.5		.30			39.9	2.4				
56	3.2	33.33	8.97	.80		1.62		36.32	1.76	38.08	11.98	1.21	3.76		99.75
57	15.0	50.25	.96	.45		.78		40.10	.66	40.76	6.20	.08	.25		99.73
59	2.5	42.75	4.32	.93		.73		38.14	.59	38.73	10.92	.67	.80		99.85
60	6.0	31.15	16.94	1.13		.55		43.01	.88	43.89	4.87	.34	1.50		100.37
24	0.8	29.37	19.10	.10		2.08		42.98	1.86	44.84	1.44	.43	2.96		100.32
M 84		32.18	14.79	5.69		1.06		44.32	.34	44.66	.56	.52	.24		99.70
85		54.49	.09	.58		.65		42.60	.77	43.37	.20	.06	.06		99.50
1		53.70	.80			Tr				43.41		.40		1.40	99.71
2		27.74	16.62			Pr				40.36		3.72		11.08	99.52
3		30.82	11.60			Pr				39.52		10.22		7.76	99.92
4		27.24	16.87			Pr				41.84		5.84		7.44	99.23
5		20.34	9.63			Pr				26.32		8.05		26.46	90.79

Notes: (1) Samples M: 43, 50, 53, 56, 57, 59, 60, 24, 84, and 85 were analyzed at Mines Branch laboratories, Ottawa.
(2) Samples M: 44, 45, 49, 51, 52, 54, and 55 were analyzed at the iron ore production laboratories, Steep Rock Lake.
(3) Analyses 1 to 5 are taken from Moore (1940, pp. 13 and 15)
(4) Values for H_2O were obtained by difference: Loss on ignition less CO_2.
(5) Tr = trace; Pr = present.

The general similarity of the Steeprock carbonate to younger sedimentary limestones and dolomites has been commented upon by many previous observers. Coleman (4) states: "One almost expects to discover fossils in them but none have been found." Subsequently, Walcott described two new forms from the Steeprock carbonate which he named *Atikokania Lawsoni* and *A. irregularis* as well as a fragment tentatively identified as *Cryptozoan ? occidentale* (11, p. 16–23). The first two forms have not received general acceptance, but the excellent new exposures revealed by lowering the lake warrant re-examination by a competent paleontologist. The *Cryptozoan ?* fragment probably came from what are much the most common organic-like forms in the Steeprock carbonate—the so-called "algal" structures. Several types occur and are particularly well-exposed in Southeast Arm. The most abundant appear onion-like in cross-section or resemble stacks of inverted

bowls and are mostly less than a foot in diameter. These, as well as similar but much larger structures (up to 50 feet across) appear on bedding planes as gentle domes (Fig. 14). The curved surfaces are convex towards the southwest. Many of the forms appear identical with those which the writer has seen in the Kona dolomite of Michigan (31, p. 345) and in the Great Slave

TABLE 2

Sample No.	Field description (by: W. G. Wegenast, 1954)	Differential thermal analyses and X-ray powder patterns	Insoluble residue after digestion in 1:3 HCl
M 43	Banded, light to dark, dense carbonate; minor introduced carbonate veins and lenses	Slightly dolomitic calcite and quartz	Fine-grained quartz, carbon, and pyrite
44	Well-banded, dense, blue-grey carbonate showing stylolites; minor introduced carbonate and pyrite crystals		
45	Well-banded, dense, dark blue-grey carbonate; bands down to ½ inch		Fine-grained quartz, carbon, and pyrite
49	Well-banded, blue-grey carbonate		Fine-grained quartz, carbon, and pyrite
50	Well-banded, blue-grey carbonate, bleached white near minor fault zone		Cubes of pyrite, anhedral quartz
51	Fault zone with white chalky gouge bordered by bleached banded carbonate		Quartz, pyrite, hematite
52	Dark blue-grey carbonate, more massive and with more widely-spaced bands than in previous sections		
53	Massive carbonate with only faint banding	Calcite and a trace of quartz	Quartz and carbon
54	Well-banded, dense, blue-grey carbonate becoming white as fault zone approached		
55	Massive carbonate with white zones near fault		
56	Fault zone: graphitic slip faces, soft decomposed material and introduced carbonate	Dolomite, calcite, quartz and graphite (?)	Quartz and iron Oxide
57	Dense, blue-grey, well-banded carbonate with introduced carbonate along bedding planes	Calcite with traces of dolomite and quartz	
59	Mottled and banded carbonate showing "algal" structures; quartz crystals line vugs in porous horizon	Calcite, very slightly ankeritic dolomite, and quartz	
60	Well-banded, mottled, and vuggy material, colored cream to black to red	Very slightly ankeritic dolomite, calcite, and quartz	Quartz crystals, cherty material, crystalline and earthy hematite
24	Mottled, highly colored, vuggy carbonate immediately below orezone in Southeast Cut at east end of "B" orebody	Dolomite	Hematite, pyrolusite, and reddish quartz
M 84	Ferrodolomite cementing breccia zone near base of carbonate, north of west end of "B" orebody	Ankeritic dolomite and calcite	
85	Calcite cementing breccia zone in same area as M 84	Calcite	
1	Blue limestone at north end of Middle Arm	Notes: (1) Thermal and X-ray analyses were made at the Mines Branch, Dept. of Mines and Technical Surveys, Ottawa (Forman and Lindsey, 1953)	
2	Ferrodolomite, northwest shore of West Arm		
3	Ferrodolomite, east side of island at north end of West Arm		
4	Ferrodolomite, north end of Middle Arm		
5	Ferrodolomite, Elbow Point (north of "B" orebody	(2) Studies of insoluble residues were made by W. G. Wegenast (1954)	

Group of the Northwest Territories, Canada (7, p. 1959, and Figs. 1 and 2, Plate 9). Such forms are commonly ascribed to the activities of primitive calcareous algae and are particularly characteristic of dolomite and limestone sediments of the middle and late Precambrian.

A series of chip samples aggregating some 175 feet were taken at intervals across a true stratigraphic thickness of about 300 feet of well-banded carbonate north of the east end of "B" orebody by W. G. Wegenast in 1952.

Proximate analyses of these were made at the Steep Rock iron ore production laboratories.[5]

Representative members of this series were analyzed at the Mines Branch,[6] Department of Mines and Technical Surveys, Ottawa (Table 1) and were further tested by differential thermal analysis and X-ray powder photography (Table 2) (8). Spectrographic studies of trace element distribution in certain samples (Table 3) were made at the Miller Spectrographic Laboratories,[7] Queen's University, Kingston.

TABLE 3

Sample No.	Mg	Ca	Sr	Ba	Al	Ga	Si	Ti	Sn	Pb	Zn	Cu	Ag	V	Cr	Mo	Mn	Fe	Co	Ni
M 45	VS	Ex	VS	?	M	—	S	Tr	—	M	—	M	—	—	—	—	S	S	—	—
51	VS	Ex	VS	?	M	—	S	W	—	M	—	M	—	—	—	—	S	S	—	—
54	VS	Ex	Ex	?	M	—	S	W	—	M	—	S	—	—	—	—	S	S	—	—
24	VS	Ex	S	S	S	—	M	M	W	M	W	S	M	—	W	Tr	VS	VS	S	S
M 84	Ex	Ex	S	M	W	Tr	M	W	W	W	Tr	M	S	M	M	W	VS	VS	W	M
85	VS	Ex	VS	S	Tr	Tr	Tr	M	W	M	—	M	M	M	Tr	M	VS	S	—	Tr

Notes: Spectrographic determination of trace elements was made at the Miller Research Laboratories, Queen's University, Kingston.

Ex = extreme S = strong W = weak ? = doubtful
VS = very strong M = moderate Tr = trace — = not detected

In addition to the analyses shown in Table 1, more than 40 samples of carbonate from various outcrops and drill intersections in Formation 3 as shown on Figure 1 have been partially analyzed at the Steep Rock iron ore production laboratories with the following mean result:

CaO	37.6%
MgO	7.3
Fe	3.6
Mn	.82
Ignition Loss	38.1
SiO_2	8.65
Al_2O_3	.23
S	.009
P	.008

Also, 11 additional differential thermal analyses have been made and these are in agreement with those tabulated. The results of the chemical, thermal and X-ray studies on 21 samples (10 of which appear in Table 2) are summarized as follows (8, p. 12):

The Steep Rock carbonates do not contain large amounts of iron and are essentially dolomites and calcites. Where iron does occur as a replacement for mag-

[5] Chemist in charge, Mr. B. J. Eyton, to whom the writer is much indebted for his assistance.

[6] To Dr. J. Convey, Director, and to Mr. S. A. Forman (Crystal Chemist) and Dr. June M. Lindsey (Physicist) who carried out the investigations, the writer wishes to express his appreciation.

[7] Established through the assistance of the Research Council of Ontario. Dr. J. E. Hawley, Director of the Miller Laboratories, not only aided in the spectrographic studies but, from a long experience in the geology of iron ore deposits, gave valued advice in the preparation of this paper.

nesium in the dolomite lattice, it is of such small amounts that the mineral is closer to dolomite than ankerite in the ankerite-dolomite solid solution series. It was therefore considered advisable to refer to them in most cases as ankeritic dolomites.

On the basis of all these results, it is quite clear that the bulk of the Steeprock carbonate is a sedimentary formation ranging in composition from an almost pure calcitic limestone to dolomite. The content of iron and manganese carbonates averages about one percent and, in part, these have been altered to the oxides. Most of the beds contain variable amounts of chert, clay minerals, and carbonaceous material. The common occurrence of "algal" (Fig. 14) and stylolitic (Fig. 13) structures, the excellent bedding displayed by most of the outcrops (Fig. 12) and the general field relations, unite in confirming a sedimentary origin.

The secondary carbonate that veins the limestone and dolomite or cements the carbonate breccia includes both coarsely crystalline pure calcite as well as ankerite ("Ferrodolomite" of earlier investigators). Some of this may be of local derivation and some probably represents hydrothermally introduced material. The two samples of unquestionably secondary carbonate listed in Table III (M 84 and M 85) show a significantly greater diversity of trace elements than all samples of sedimentary carbonate save that immediately beneath the orezone.

The contact of the carbonate member with the overlying footwall phase of the orezone is sharply defined (Fig. 15: D). Broadly considered it conforms with the bedding in the carbonate; in detail, it is most irregular and transgressive with local "relief" on the surface of the contact amounting to some tens of feet. Rounded protuberances of carbonate extend up into the orezone, and, conversely, salients of footwall "paint" extend irregularly down into the carbonate. This contact is regarded as an ancient "Karst" surface with pinnacles and sinkholes developed by exposure of the originally flat-lying carbonate to the solution effects of deep weathering, and the overlying footwall "paint" of the orezone is considered to be mainly of residual accumulation.

Hanging-Wall Rocks.—The "orezone," which succeeds the carbonate, is described elsewhere; it is followed to the southwest by what may be termed the hanging-wall rocks. These are poorly exposed at the surface, but are cross-sectioned for upwards of 2,000 feet on each of the three levels presently under development at Errington No. 1 shaft ("B" orezone).[8] In general, the hanging-wall rocks show extreme variability with intimately interbanded slate, grit, conglomerate, tuff, agglomerate, pillowed and massive flows, and basic sills. In this assemblage the only reasonably continuous and unique marker is the so-called "ashrock," which forms the immediate hanging-wall of the "B," "C," "G," "E," and "F" zones but seems lacking in at least the western part of the "A" zone where a more silicic pyroclastic bounds the orezone on the southwest.

The ashrock presents many unusual lithologic features. A typical specimen shows closely-packed, dark green to black, lenticular, aphanitic, serpen-

[8] The geology of Errington Shaft was mapped by W. J. Huston and the writer in 1952. Grateful acknowledgment is made to Mr. Huston for his geological plans of the various levels and for his many other contributions to the general study of Steep Rock geology.

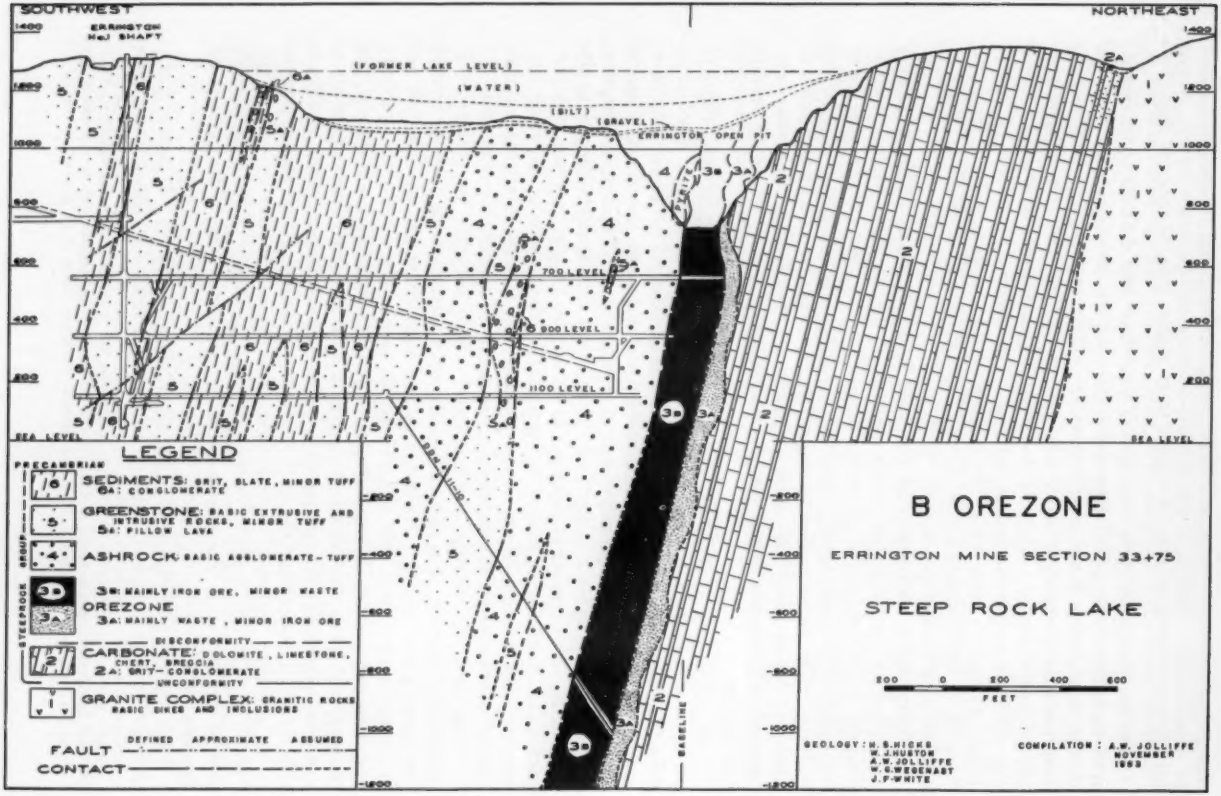

FIG. 3. "B" Orezone—Errington Mine Section 33 + 75.

tinized fragments averaging less than one-half inch across, in a greenish schistose matrix that may show tiny white carbonate patches. Rare, larger fragments, up to a foot across, appear to be of definitely volcanic material, but a few well-rounded fragments up to three inches long were found, which appear to be altered granite. Most exposures are homogeneous with relatively evenly-sized fragments and, rarely, may show rude banding. Chemical analyses of two representative samples are shown in Table 4. If the rock is a pyroclastic, as seems most likely, the low content of silica indicates that it is an unusually basic type, approaching a picrite in composition.

TABLE 4

ANALYSES OF ASHROCK *

	(1)	(2)
SiO_2	37.28	41.32
TiO_2	.395	.48
Al_2O_3	8.28	7.78
Fe_2O_3	5.06	4.93
FeO	11.91	13.23
MgO	19.32	15.78
MnO	.34	.28
CaO	6.12	3.08
Na_2O	.14	.15
K_2O	.78	.72
CO_2	3.02	3.78
S	.048	.19
As	None	.081
P_2O_5	.076	.134
H_2O-	.06	.28
H_2O+	7.09	7.78

(1) From drill hole B50-289, hanging wall of "G" orezone.
(2) From Errington pit, hanging wall of "B" orezone.

* The analyses were made at the Mines Branch, Department of Mines and Technical Surveys, Ottawa; J. A. Fournier, Chief Chemist.

Three contrasting types of alteration are found in the ashrock. In one, the typical dark green color becomes red or brown with the development of hematite or limonite accompanied by a net increase in iron content and a corresponding decrease in silica. This change is ascribed to the oxidizing effects of meteoric waters, but is not necessarily wholly related to the present erosion surface or water table. In another type of alteration the rock becomes bleached to a very light-green color but still retains its fragmental appearance. The third type consists of replacement by pyrite. Both fragments and matrix may undergo this change and the replacement may range from a few scattered cubes of pyrite in the matrix to almost complete substitution. Even in the latter, the characteristic structures of the ashrock are preserved (Fig. 8). Such replacements may occur as discontinuous lenses anywhere within the ashrock but seem most common near its contact with the orezone. Some of the pyritic lenses are accompanied by notable amounts of hematite.

Southwest from "B" ore body the ashrock measures about 800 feet thick and contains very basic serpentinized lava flows (Fig. 3). In several places pillow shapes suggest that the original tops of these flows face southwest. The next 1,300 feet consist of sediments, flows, tuffs, and sills. The propor-

tion of thick, massive basic flows and/or sills increases towards the south, and such rocks underlie the topographic eminence of Float Ore "Island" on which Errington No. 1 shaft is situated. Several minor bands of clastic sediments here include slate, grit, and granite-pebble-bearing conglomerate. Grain gradations in some of these beds are in conflict with all other stratigraphic determinations elsewhere in the area, in that they suggest that the original tops face northeast.

STRUCTURE

Throughout the area mapped in the present investigation the various members of the Steeprock group strike generally northwesterly and dip steeply to the southwest. The structure is regarded, tentatively, as homoclinal with successively younger formations encountered towards the southwest. The unconformable relations with the granitic complex, grain gradations within the basal conglomerate and grits, shapes of "algal" structures in the limestone and dolomite, the erosional disconformity at the base of the orezone, and the pillow shapes in the ashrock flows unite in supporting this view. However, the grain gradations on Float Ore "Island" indicate the reverse, and, at the moment, no reasonable way out of the impasse is evident. Lawson (11, p. 12, 14) postulates a synclinal structure for the Steeprock group, the northeast limb resting on the granitic complex, and the southwest limb upon the Keewatin greenstones. Moore (15, p. 19–21) presents a similar interpretation. If the granite-pebble-bearing conglomerate on Float Ore "Island" were correlated with that at the base of the carbonate, some support would be lent to this concept. However, such a correlation would give rise to other serious problems, such as the complete lack of similarity between the two limbs, the absence of any suggestion of closure with depth or any indications of axial plane structures (cf. Fig. 3).

Only part of the area underlain by the Steeprock formations has been mapped in detail and the upper boundary of the group is in doubt. With these limitations, the present findings concerning the structural history of the area are in closest agreement with those of Smyth (24), viz. that the group was first tilted to its present steep southwesterly dip and then compressed from the northwest. This produced a regional northeasterly-trending foliation in suitable members of the hanging-wall rocks, in some bands of aluminous sediments within the ore (Fig. 9), and in the pre-Steeprock granitic complex. Also ascribed to this period of compression are the relatively sharp flexures that are marked by local attenuation of the "orezone" and brecciation of the carbonate. Since the trend of the regional foliation lies about tangential to the margin of the post-Steeprock granite northwest of the Lake (Fig. 2), the period of compression may have coincided with emplacement of this batholith.

Most faults in the area strike northeasterly, dip steeply, and are younger than members of the Steeprock group (including the iron ores). Movements along these have been dominantly lateral and have resulted in left-hand strike separations (the western sides moved relatively southwards). The gently sinuous courses followed by these faults across areas of moderately high relief imply steep dips and this inference is supported by such direct measurements

as are available. On the peninsula separating the north ends of West and Middle Arms the Bartley Fault has an established dip of about 75° to SE. However, only 1,000 feet northeast along this fault its surface exposure lies almost vertically above its intersection in two drill holes. Immediately north of the lake steep northwesterly dips for both the Bartley and Samuel faults are suggested by the topography.

Brecciation, shearing, mud seams, and vein fillings mark the rare fault exposures. At the north end of Falls Bay the Samuel Fault shows up to six inches of silicified vein breccia, rusty gouge, and schist, bounded on the west by about 10 feet of brecciated granite and basic dike material, and on the east by massive carbonate. Two exposures of the Bartley Fault are marked by about five feet of breccia traversed by several mud seams up to two inches wide. Despite the magnitude of the faulting, the brecciation is rarely sufficiently intense to mask the rock type and most of the movements seem to have taken place along the narrow mud seams.

Some thrust faults dipping moderately to the south have been encountered in the underground workings (Fig. 3).

STEEPROCK "OREZONE"

Much the most interesting and economically important formation of the area lies between the carbonate and ashrock, and is appropriately called the "orezone" since it holds all the known iron orebodies of the area."[9] Throughout its explored length and to the greatest depths tested by drilling (more than 2,000 feet) it behaves like a stratigraphic member of the Steeprock group—it parallels adjacent formations in both strike and dip, it has been affected by the same folds and faults, and, finally, it shows mineral associations and alterations about equivalent in grade and character to those in other members of the group.

Except where it has been interrupted by faults, the continuity of the orezone has been established with reasonable certainty for a four-mile strike length from the northwest corner of Middle Arm to the entrance of Southeast Arm. Further extensions may be inferred from certain isolated drillholes in West and Southeast Arms and from the general geological relations in these areas and elsewhere. The subdivision of this single continuous stratigraphic member into the "A," "B," "C," and other orezones reflect an early concept of disconnected ore-bodies, now known to be erroneous. This continuity may justify the application of the term "range" to the Steeprock orezone although this member is invariably marked by a topographic depression, and many features, such as the mineralogy and relative proportions of ore to waste, greatly differ from those in the ferruginous members of other Lake Superior ranges.

[9] None of the sulphide or sulphide-oxide lenses well out in the hangingwall rocks has yet been proven to be of ore grade and dimensions. Some oxide ore lenses, apparently surrounded by ashrock immediately adjacent to the "B" orebody underground, are tentatively regarded as having been separated from the orezone by deformation—flowage of the incompetent ashrock around lenses of hard lump ore during folding.

Excluding interruptions due to faulting, within the more closely explored four miles of strike length, at no place has the orezone been shown to be absent, and only four relatively short sections are known where it becomes markedly attenuated—midway along "G" orezone, at two places in the eastern part of "B" orezone, and at the entrance to Southeast Arm. These sections are all characterized by anomalous northeasterly strikes, and a sharp Z-shaped fold (plus minor faulting) seems the most reasonable interpretation in each case. Three of these four sections show undue development of pyrite replacing hanging-wall rocks and extending into the orezone itself.

Until nine years ago actual examination of orezone rocks could be made only on pieces of float on the south shore of the lake (which played so important a part in the discovery of the range) and on material recovered by drilling. Since less than ten per cent of the orezone is sufficiently coherent to yield either float or core, no representative picture could be obtained. Now, however, with several hundred feet opened up along "A" orezone and more than three thousand feet along "B" orezone a truly remarkable pattern is disclosed, which is consistent with that suggested by drilling results obtained elsewhere in the range.

Throughout its reasonably well-explored length of four miles in Middle Arm and Falls Bay, the orezone averages several hundred feet wide and shows two distinct members: a southwestern or hanging-wall part that is mostly iron ore with only minor waste, and a northeastern or footwall part that is mostly waste although lenses of ore grade material may occur in it. The same two-fold division is reflected in the distribution of manganese. With few exceptions, the ore (and minor waste) in the hanging-wall part contains negligible manganese (0.3% or less), whereas the footwall member (particularly the waste) averages more than two percent. The change from relatively low to relatively high manganese is usually abrupt and is designated as the "manganese line," which may be regarded as marking the lower (northeastern) boundary of the economically more important hanging-wall part of the orezone.

The disposition of ore and waste in a small part of the hanging-wall member of the newly-exposed "A" orezone is indicated in Figure 4. The separation between ore and waste is commonly abrupt. When it is considered that the ore bands in Figure 4 average more than sixty percent iron, and that the chief iron mineral present is goethite, which can contain no more than 62.85 percent iron, the remarkable mineralogical purity becomes evident.

The three main types of waste in ore so far recognized are illustrated in Figure 4. Those marked "B" are well- and thinly-bedded, siliceous and aluminous sediments. The irregular body designated "A" is of a type not hitherto encountered and is tentatively regarded as a highly altered aplitic intrusion related to the post-Steeprock "Algoman" granite that outcrops about three miles to the west. The bands marked "S" contain abundant pyrite but their distribution here is hardly typical since such bodies are much more common well within the hanging-wall rocks or along the contact of these with the orezone.

The dip of the orezone here is about 75° to 80° southwest, as established by a drill hole that yielded an ore intersection more than 1,200 feet below

ledge. The maximum width of the orezone in this vicinity may be as much as 1,000 feet but the relative widths of its hanging-wall and foot-wall parts have not yet been established. However, the drill intersections plotted on Figure 4 show a high proportion of ore-grade material and a negligible manganese content, suggesting that the width of the economically important hanging-wall part of the "A" orezone here exceeds 300 feet.[10]

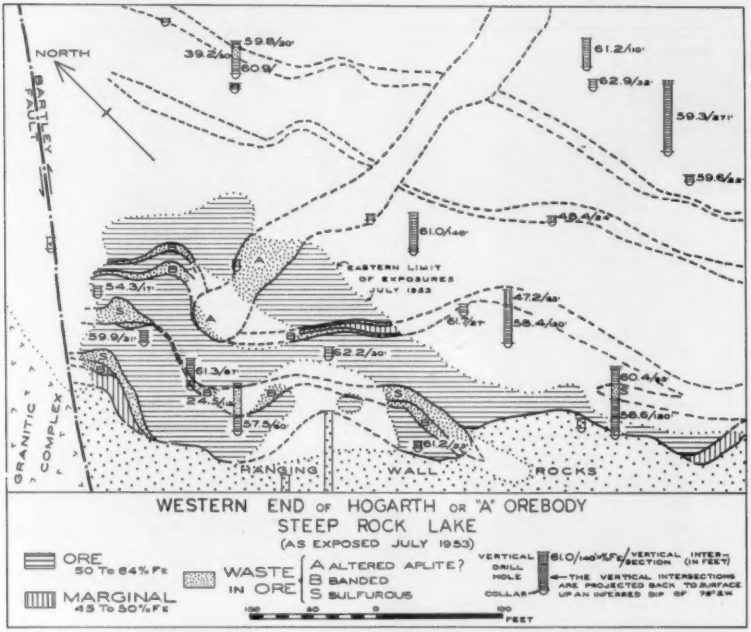

FIG. 4. Western end of Hogarth or "A" orebody, Steep Rock Lake.

A cross-section of "B" orezone is shown in Figure 3, which illustrates the typical two-fold division of the orezone, with the hanging-wall side mainly ore and the foot-wall side mainly manganiferous waste. The section also shows a typical pyritic lens encountered in hanging-wall rocks in the original open cut.

The mineralogy of the orezone appears to be relatively simple. However, since most material in it is relatively incoherent, ordinary methods of mineral determination, such as the examination of thin and polished sections, are of limited applicability and have to be supplemented by mechanical analysis, heavy mineral separations, thermal and X-ray studies. Only minor investigations of this latter type have been done thus far, so additional minerals un-

[10] Substantiated by further stripping in 1953–4.

doubtedly will be found in the orezone, but, probably, only as minor accessories.

Orezone minerals identified to date are goethite (including soft material that may be designated as limonite), hematite (including specularite), pyrite, quartz, chert, jasper, carbonaceous material,undifferentiated hydrous aluminous silicates and oxides (in part at least, kaolinite and gibbsite), and pyrolusite (in part polianite).

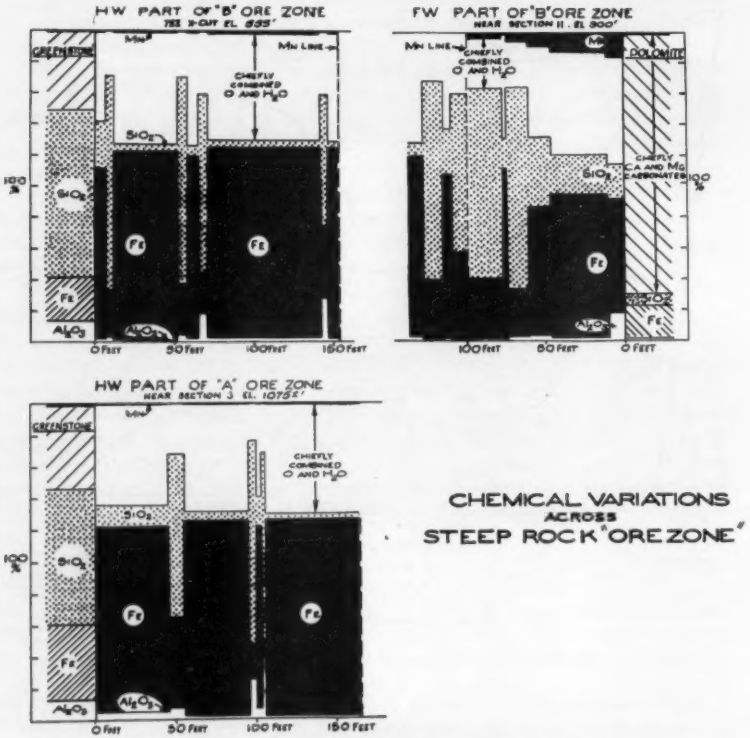

FIG. 5. Chemical variations across Steep Rock "orezone."

Of the above, goethite and hematite are most abundant in the southwestern or hanging-wall part of the orezone with goethite being much the more common. Hematite is in excess of goethite only along parts of the hanging-wall contact, particularly in the vicinity of pyritic lenses. Within the orezone most of the ore is goethite and shows a variety of brecciated, fragmental, vuggy, and colloform structures (Figs. 16–18). Most fragments are less than an inch across and are composed of extremely fine-grained, compact, hard, goethite within a matrix that ranges from earthy to crystalline hematite or goethite.

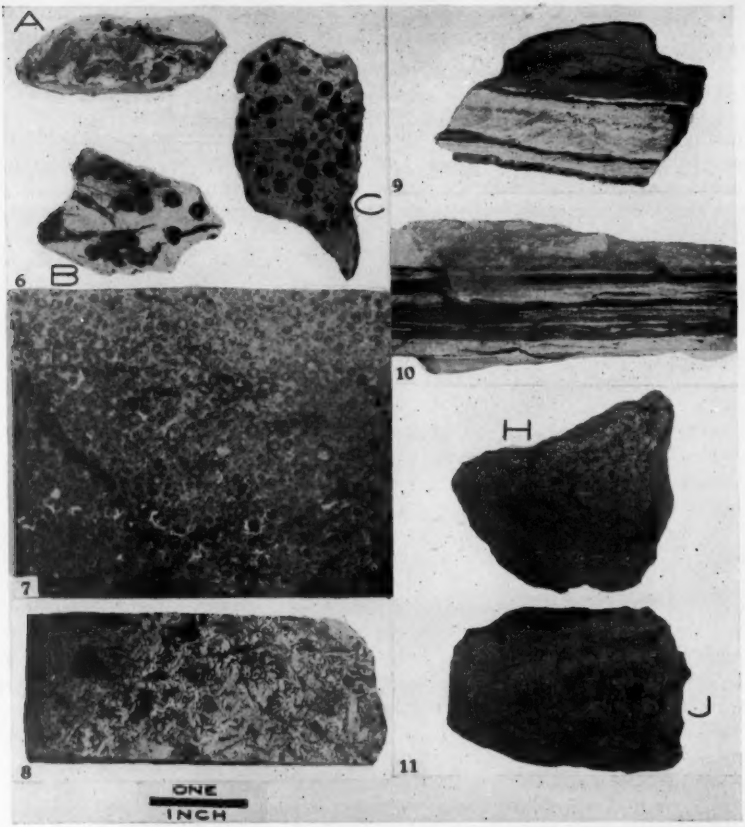

FIG. 6. A, B. Pisolitic material from band of soft, siliceous, clay sediments within "A" orebody.

FIG. 6. C, and FIG. 7. "Buckshot" waste from No. 7 stockpile—presumably originally from near the hanging-wall side of "B" orebody. Both true pisolites and clastic fragments are present and are mostly hematite. C contains gibbsite.

FIG. 8. Pyrite (light) and cherty material (dark) showing structures suggestive of replaced ashrock; from hanging-wall rocks "G" orezone.

FIGS. 9, 10. Well-banded sediments in "A" orebody. The dark bands mainly represent hematitic staining of siliceous and clayey material. 10 shows well-developed cleavage parallel to regional northeasterly foliation.

FIG. 11. Manganiferous footwall waste, "B" orezone. H shows a band of fine-pebble conglomerate whose fragments are mostly well-rounded hematite resting on fine-grained clastic material. J illustrates the discontinuous thin laminations most common near the contact with the underlying carbonate.

In vuggy ore, similar dense aphanitic goethite commonly shows a transition to perfectly formed tiny goethite crystals projecting into the vugs (Fig. 16). Other vugs may be lined by colloform goethite, by specularite, or by quartz crystals (Figs. 17, 18).

In the foot-wall part of the orezone both goethite and hematite occur as earthy incoherent material. In addition, round to sub-angular grains, pebbles, and boulders of hematite, obviously representing transported clastic material, occur in certain bands near the contact with the carbonate.

The silica minerals in the orezone show various modes of occurrence. Some of the banded waste contains thinly-bedded chert. Much of this shows brecciation, although generally not sufficiently intense to mask the stratigraphical continuity of the beds. Other silica-rich waste bands are soft and incoherent, and are composed of such finely divided material as to be nearly as plastic as clay. Particularly in the foot-wall part of the orezone, well-rounded to sub-angular clastic grains of quartz and chert occur. Finally, tiny euhedral quartz crystals are found lining some vugs in the porous ore and waste.

The only manganese mineral identified is pyrolusite which seems largely restricted to the foot-wall part of the orezone. Some of this is the crystalline polianite variety (5), which occurs in veins cutting both the foot-wall waste and the underlying carbonate rocks, but most of it occurs as black, earthy material scattered through the foot-wall waste in much the same fashion as the much less abundant black carbonaceous material.

Aluminous minerals are common in the waste bands in ore as well as within the foot-wall waste. A few of the aluminous bands show definite pisolitic structures (Fig. 6). Most of the iron ores contain only about one per cent alumina, but particularly near the upper contact with hanging-wall rocks a notable rise in alumina is common, in places sufficient to lower the iron content to below ore grade. Irregular lenses of such material were encountered along the hanging-wall of "B" orezone in the west-central part of the open pit and also appear in similar positions on the 700 and 900 levels underground. Specimens of this show a mixture of dark hematite pisolites and fragments within a lighter colored aluminous matrix in which kaolinite and gibbsite have been identified by X-ray methods.[11] In this material the titanium content (which is negligible in most of the ore) exceeds two percent. Such pisolitic and fragmental material (known by the local term of "buckshot ore and waste") resembles, both in outward appearance and in chemical and mineral content, a ferruginous bauxite.

Pyrite is relatively rare within the orezone and seems to be associated either with tight Z-shaped folds involving orezone or with certain sedimentary waste bands (Fig. 4). In the latter, the pyrite occurs as a rather soft, fine-grained, dark green aggregate. Within and along the hanging-wall rocks the pyrite (with minor hematite) forms hard siliceous replacement bodies, some of which show preservation of ashrock structures (Fig. 8).

[11] Personal communication from W. K. Gummer, Chief, Ore Dressing Division, Aluminium Laboratories, Arvida, Que.

Of particular significance is the anomalous paragenesis found in most polished sections and hand specimens of the ores. Although local reversals do occur, the general sequence is fine-grained massive goethite (oldest) followed by more coarsely crystalline or soft goethite, hematite, and pyrite (youngest).

Mineralogical variations across the orezone are naturally paralleled by chemical variations. Three partial sections are shown in Figure 5; the footages recorded represent approximate true widths of orezone material sampled.

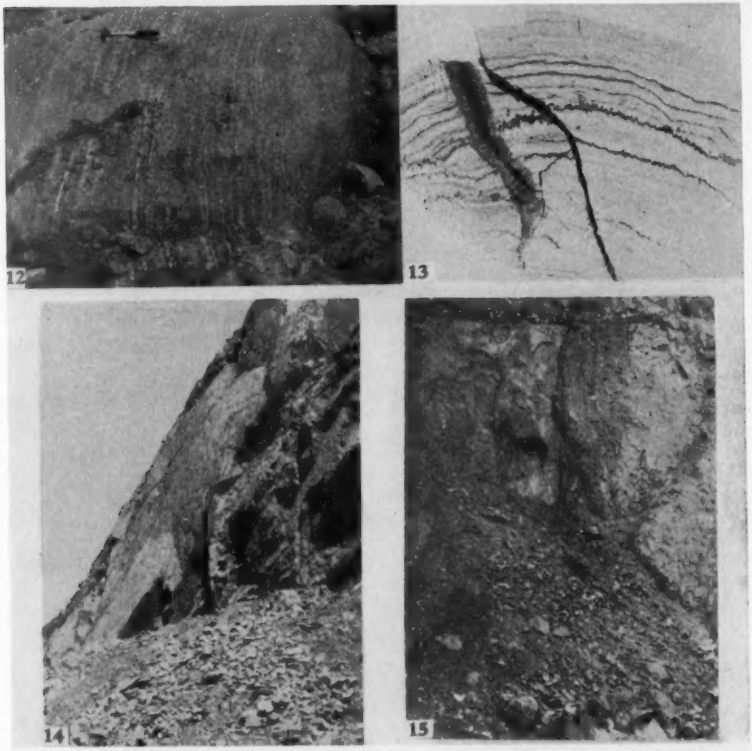

FIG. 12. Thinly banded carbonate north of "A" ore-body.

FIG. 13. Stylolite structures in carbonate. Transmitted light. × 3.

FIG. 14. "Algal" structures in carbonate, footwall of "B" ore-body. Smooth surface at left is a bedding plane showing domal protuberances about two feet across superimposed on larger domes up to 50 feet across. All these are convex to the south. (Photograph by W. G. Wegenast.)

FIG. 15. Contact of carbonate with manganiferous footwall waste of "B" orezone. At right is rudely banded, partly fragmental, soft waste; at left is the irregular upper surface of the carbonate from which the waste has been stripped. (Photograph by W. G. Wegenast.)

The first section illustrates changes in chemical content across the hanging-wall part of "B" orezone in 722 crosscut. This represents the full width of the hanging-wall member here since the crosscut terminates against manganiferous waste. The second section is across only part of the hanging-wall mem-

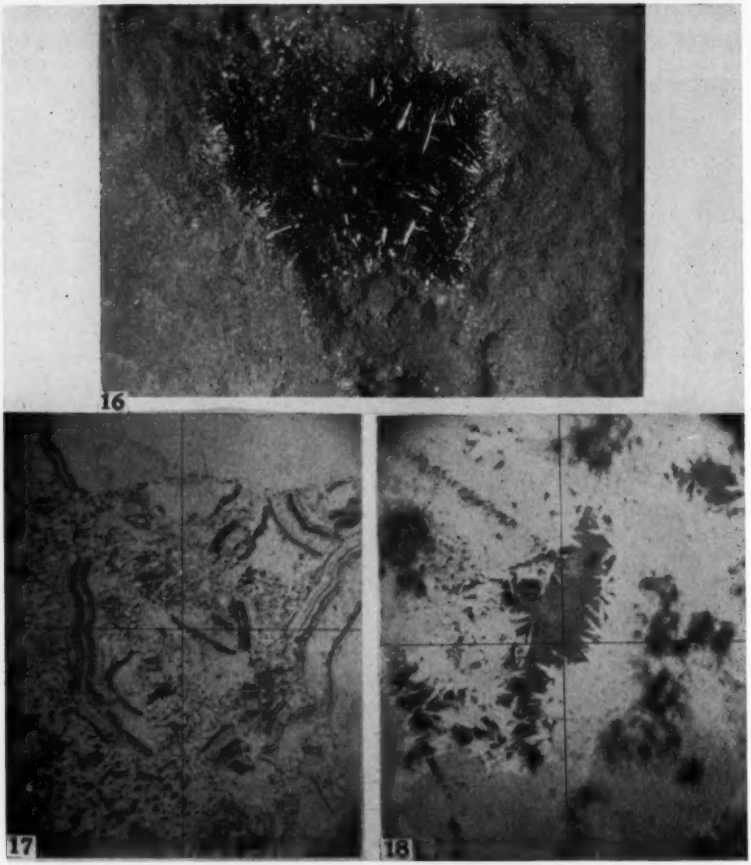

FIG. 16. Goethite crystals lining vug in fine-grained goethite; "A" ore-body. × 15.

FIG. 17. Brecciated massive (light grey) and colloform (banded) goethite cemented by soft goethite (pitted surface). Float ore south of Falls Bay, presumably from "C" ore-body. × 128.

FIG. 18. Massive goethite (light grey) veined by specular hematite (white) which shows freely-terminating crystals lining vug now filled with quartz (dark grey); "G" ore-body. × 250.

ber of the "A" orezone; the "manganese line" here lies more than 200 feet farther northeast. Although this latter section is about two miles northwest of the first and some 500 feet higher in elevation, both of them display the same general pattern—in each case the bands of ore-grade material average 60.8 percent iron, the relatively narrow bands of waste are obviously mostly clay minerals and silica, and the manganese content is negligible.

The remaining section represents the foot-wall part of "B" orezone about 1,800 feet southeast of 722 crosscut and about 350 feet higher. The iron content is mostly below ore grade due to siliceous and aluminous impurities, whereas the manganese is markedly high. Also shown is the chemical composition of the limestone-dolomite which lies in erosional disconformity immediately below the orezone. The manganese, silica, iron, and alumina are seen to be in about the same relative proportions in the carbonate as in the overlying foot-wall waste. That is, weathering of carbonate of this composition by solution and removal of lime and magnesia would leave a regolith of much the same chemical composition as is represented by the foot-wall waste member of the orezone.

CONCLUSION

It should be emphasized that space has hardly permitted a balanced presentation here, only the new data have been particularly stressed. In their classic reports on the area, Roberts and Bartley described a variety of hydrothermal features in Steep Rock ores and the fact that only some of these have been mentioned here is not to deny their existence. Many additional examples of such phenomena were encountered in the present investigation and bear witness to the excellence of this early study, made before any examination of ore in place was possible. These evidences of hydrothermal activity led Roberts and Bartley to postulate formation of the Steep Rock ores by hydrothermal replacement of breccia along a faulted zone of unconformity. The new information made available by mining operations now necessitates certain revisions in this theory.

As far as the broad field relations are concerned:—since the ore bodies seem restricted to a stratigraphic member of the Steeprock group, and since most of the non-ore parts of the orezone are almost certainly of sedimentary origin (including both residual sedimentary material derived from the weathering of the underlying impure limestone-dolomite, as well as transported clastic sedimentary material), a possible sedimentary origin for the co-extensive iron ore bands themselves must at least be entertained. Support for this possibility is supplied by the mineral associations and their textures—particularly the dominance of goethite and its anomalous early position in a sequence of mineral deposition that is precisely the reverse of normal hydrothermal paragenesis; the lack of evidence that the great bulk of the goethite was developed by the alteration of any pre-existing mineral or by the replacement of any pre-existing rock; and, finally, the presence of kaolin and gibbsite in certain marginal ores and waste which show pisolitic structures and abnormally high titanium content typical of sedimentary ferruginous bauxites.

Accordingly, the sequence of events which led to the formation of the iron

ores now appears to be as summarized below. After the deposition of the slightly ferruginous and manganiferous limestone-dolomite member of the Steeprock group, this was uplifted and exposed to long-continued deep weathering, resulting in the formation of a thick residual mantle now largely incorporated in the foot-wall part of the Steeprock orezone. As the area once again sank beneath the sea, this material was partially reworked by waves and currents in the shallow waters encroaching on it. Following this, ferruginous material in vast quantities was carried into this basin (possibly furnished by erosion of areas of the iron-rich residual mantle remaining exposed above water elsewhere) and was there precipitated chemically or biochemically as remarkably pure limonite. During this accumulation, minor interruptions by short periods of more normal sedimentation would account for the relatively narrow beds of cherty and aluminous sediments that now form bands of waste in ore, and exposure of the latter to uplift and weathering might account for the local pisolitic laterite. All this was abruptly terminated by the volcanic eruptions that formed the ashrock and associated pyroclastics. Subsequently, the whole Steeprock group was deformed and altered during the orogeny that accompanied emplacement of a granite batholith, the nearest outcrops of which now lie two miles northwest of the lake. This deformation was sufficiently intense to produce nearly vertical dips in members of the group, foliation in some of the ashrock and slate, and brecciation in some of the carbonate and limonite. Hydrothermal solutions sweeping outwards from the granitic body would be competent to change some of the limonite to recognizably crystalline goethite and, provided that temperatures of about 150° C were attained (30, 22) to convert some of it to hematite. Such a transformation would proceed most readily in the more finely comminuted matrix of the limonite breccia and, if not carried to completion, would leave the larger hard limonite fragments (in part showing goethite crystals) surrounded by paragenetically later hematite. With declining temperatures minor reversals in this common sequence would be expected. These are the features that Steep Rock ores now display.

Furthermore, these same hydrothermal solutions probably carried sulfur and the resultant pyrite would show the relationships it now exhibits in the ores—veining the oxides and characteristically bordered by hematite rather than goethite (as witness the suggestive juxtaposition of hard hematite lump ore around pyritic bodies along the hanging-wall of the orezone). Tentatively, the development of pyrite-hematite lenses outside the orezone may likewise be ascribed to these solutions, perhaps iron-enriched from passing through the orezone. The preservation of typical ashrock structures in some of these lenses affords conclusive evidence of replacement. In any case, the migration of some iron as oxide seems necessary to explain certain field relationships such as veinlets of hematite penetrating chert and ashrock, lenses of iron oxides in the hanging-wall rocks, etc., but the iron may well have been derived from that already concentrated in the orezone by processes of sedimentation, rather than supplied by an extraneous igneous source.

Much later than the formation of the Steep Rock ores, the whole folded group was broken into a number of segments by northeasterly-trending faults.

Displacements along these were dominantly lateral and resulted in strike separations of up to more than two miles.

This interpretation of the events that ultimately led to the formation of the Steep Rock ores is a tentative one and was arrived at independently, although a re-examination of the literature reveals that certain parts of it were suggested previously by Hawley,[12] Schofield,[12] and F. Gordon Smith (21). Admittedly, it still leaves many problems unanswered, and the three most obvious of these concern: The manner of transportation of iron prior to its precipitation; why it was precipitated as limonite rather than as a silicate, carbonate, or non-hydrous oxide; and how limonite deposited in Precambrian time could possibly be preserved as such.

The first of these is just part of the formidable (and perennial) problem of abnormal transportation of iron within Precambrian times. Concerning the second—although most Precambrian ferruginous sediments indicate that the iron was deposited as a silicate, carbonate, or oxide rather than limonite, the probable deposition in the same era of this most widespread of all sedimentary iron minerals can hardly be doubted. Finally, the survival of Precambrian limonite as such despite deformation and metamorphism at first sight seems about as improbable as the preservation of peat in Carboniferous rocks. However, the transformation of goethite to hematite is practically independent of pressure and will not take place until temperatures of about 150° C are attained (22). That the temperatures experienced by the Steeprock group were moderate to low is evidenced by the complete lack of interaction between the finely-divided clay and chert minerals with carbonate in the impure limestone-dolomite, and by the notably low grade of alteration in ashrock and other members.

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THE LEAD–ZINC VEINS OF THE CHILETE MINING DISTRICT IN NORTHERN PERU[1]

FRANK S. SIMONS

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ABSTRACT

Lead-zinc-silver veins in the Chilete mining district in the Department of Cajamarca in northern Peru have been worked sporadically since the 17th century, but the greatest activity dates only from 1951. The ore deposits are in a thick section of andesitic volcanic rocks that overlie with marked unconformity a sequence of Cretaceous limestone, shale, and quartzite. The volcanic rocks form a gently north-dipping block of apparently simple structure. The Chilete deposits are quartz-sulfide veins consisting essentially of sphalerite, pyrite, and galena in a gangue of quartz and silicified and pyritized andesite. Wall rocks are calcitized, chloritized, pyritized, and sericitized. The veins were formed by fissure filling, breccia filling, and replacement. Veins strike either northwest or east-northeast and dip steeply. They range from a few centimeters to 4 m in width and the longest has a strike length of about 1,700 m. The veins are cut by a number of post-mineral strike-slip faults of small displacement. Thicker sections of the principal northwest-striking vein, Murcielago, tend to occur where the strike swings slightly to the north. Vein intersections are not favorable loci for ore deposition, and several intersections seem to be distinctly unfavorable. All the veins have roughly the same combined content of lead and zinc at all levels, but the proportion of zinc to lead increases notably at the lowest levels of exploration, 200–250 m below the outcrops.

[1] Publication authorized by the Director, U. S. Geological Survey.

INTRODUCTION

LEAD-ZINC veins are being worked in the Chilete mining district, near the town of Chilete on the Rio Magdalena in the Department of Cajamarca in northern Peru. Chilete lies on the main road between Pacasmayo and Cajamarca 108 km east of Pacasmayo. The altitude of Chilete is about 1,100 m and the mountains in the vicinity rise to well over 2,200 m. The district is one of the few lead and zinc producers in Peru whose altitudes are less than 4,000 m. In general the terrain is rugged but relatively easy of access via numerous trails. The climate is warm throughout the year, with temperatures ranging from 15° to 35° C. Annual rainfall is 20–25 cm, most of which occurs from January to April. In general the region is rather arid.

The only mining activity in the district is the operation of the Northern Peru Mining & Smelting Co., a subsidiary of the American Smelting & Refining Co., at Paredones in the San Pablo Valley 4 km north of Chilete. The veins at Paredones have yielded most of the lead, zinc, and silver mined in the district since its discovery in the 17th century.

Eight weeks was spent in the area during 1952 and 1953. Field work included a geological reconnaissance of an area of some 50 sq km and detailed mapping on surface and underground in the Paredones area. Surface mapping was done on aerial photographs and a topographic base of the Paredones area, both furnished by the company, and underground mapping was done on company maps on a scale of 1 : 500. A surface map was compiled from the aerial photographs on a scale of 1 : 10,000 using an Abrams mechanical triangulator kit. Housing and subsistence were kindly provided by the company.

Acknowledgments.—It is a pleasure to acknowledge the wholehearted cooperation of the Northern Peru Mining & Smelting Co. during my study of Chilete. I am especially indebted to Mr. Lawson Entwistle, Chief Geologist of the company, who made arrangements for my work and discussed many of the geological problems with me, and to Mr. Willis Griswold, then General Manager of Operations at Chilete, for much friendly assistance and stimulating discussions.

The study of the Chilete district was undertaken as part of a more comprehensive study of the lead and zinc resources of Peru, which has been carried out by the U. S. Geological Survey in collaboration with the Geological Institute of Peru during the past 7 years. This work is at present done under the auspices of the Foreign Operations Administration of the U. S. Department of State.

GENERAL GEOLOGY

The oldest rocks in the district are a sequence of limestones and quartzites of Cretaceous age, which crop out along and south of the Rio Magdalena (Fig. 1). These rocks were not studied in detail. The upper part of the section consists of thin-bedded dark-gray to black impure limestone and interbedded gray shale that strikes west-northwest and dips 30°–60° south. The limestone is at least 1,500 m thick. The lower part of the section is made

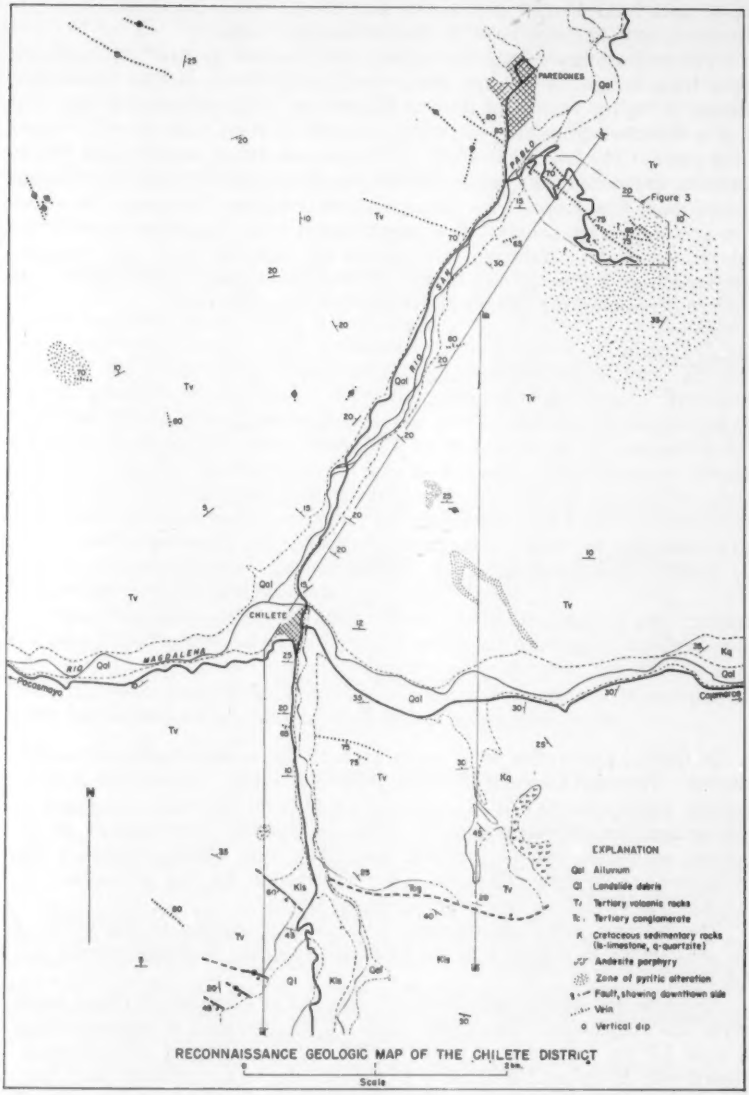

PAREDONES
Qal
Figure 3
Tv
CHILETE
RIO MAGDALENA
Pacomayo
Cajamarca
Kq
Kis
Ql
N
EXPLANATION
Qal Aluvium
Ql Landslide debris
Tv Tertiary volcanic rocks
Tc Tertiary conglomerate
K Cretaceous sedimentary rocks (ls-limestone, q-quartzite)
Andesite porphyry
Zone of pyritic alteration
Fault, showing downthrown side
Vein
o Vertical dip
RECONNAISSANCE GEOLOGIC MAP OF THE CHILETE DISTRICT
Scale

FIG. 1.

up of thick-bedded white quartzite at least 500 or 600 m thick. No mineralization of any kind was noted in the sedimentary rocks.

The sedimentary section is overlain with marked angular unconformity by a thick section of volcanic rocks, which underlie almost the entire area shown in Figure 1 north of the Rio Magdalena. The thickness of this section is estimated from the generalized structure sections (Fig. 2) to be 1,500 m or more. The lower 300–400 m is composed of interlayered andesite flows, andesite and dacite tuffs, and quartzite conglomerates with only very minor quantities of flow breccia. In contrast, above this layered sequence, the rocks are almost entirely andesitic flow breccias and lavas that show little or no layered structure. Although attitudes of the volcanic rocks are variable, the section in a general way forms a homocline dipping gently north. All the ore deposits of the district are enclosed in volcanic rocks.

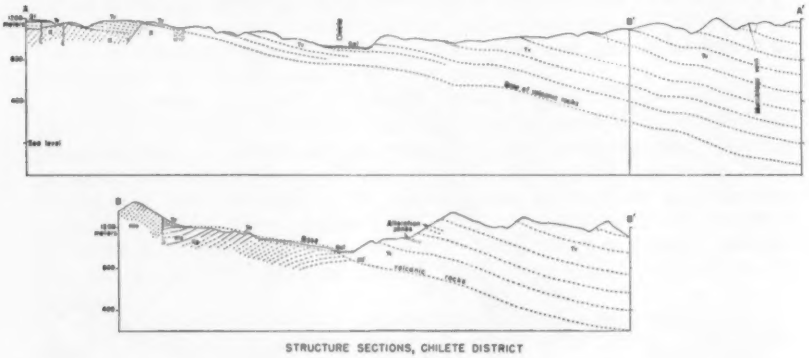


FIG. 2.

In spite of their rather fresh appearance, all the volcanic rocks are notably altered. The most common alteration product is calcite, followed by chlorite, sericite, and kaolin clay in that order. In most of the rocks examined in thin section, the original plagioclase feldspars have been converted to an aggregate of calcite, epidote, sericite, and albite, and almost invariably the pyroxenes are strongly chloritized. No explanation for this widespread alteration was offered by field observations at Chilete.

The volcanic rocks are overlain, perhaps conformably, to the north of the area shown in Figure 1 by an unstudied sequence of conglomerates and red beds.

Andesitic and dacitic intrusive rocks crop out at a number of places south of the Rio Magdalena. The largest mass is a dikelike body of augite andesite at least 1.5 km long and as much as 350 m wide, intruded into quartzite. Several sills 50 cm to 2 m thick of porphyritic dacite are intruded into limestone. The andesites are younger than the basal volcanic rocks; the age of the dacite relative to the volcanic rocks is not known, but the basal volcanic section contains tuffaceous rocks of similar composition.

A few faults of small displacement cut sedimentary and volcanic rocks south of the Rio Magdalena and offset veins in the Paredones area; north of the Rio Magdalena no faults of any consequence were recognized outside the mineralized area at Paredones. The sedimentary rocks are probably folded to a considerable extent, but within the studied area these rocks are largely covered by volcanics, so that few data were available. The volcanic rocks appear to be gently folded, but except in the basal part of the volcanic section their attitudes could not be determined with much assurance.

ORE DEPOSITS

All the ore deposits at Chilete are quartz-sulfide veins carrying zinc, lead, silver, and a little copper. The veins range in strike length from a few meters to 1,700 m and attain a maximum width of about 4 m. Greatest depth below the outcrop thus far reached during mining is about 245 m. Most of the veins strike either northwest or east-northeast and all dip steeply, generally 60° or more. Vein mineralogy is very simple. The only abundant sulfides are sphalerite, galena, and pyrite; chalcopyrite occurs megascopically in only four veins, although it is ubiquitous as microscopic inclusions in sphalerite; arsenopyrite was seen in one vein. The gangue is almost entirely quartz or silicified and pyritized andesite. Small amounts of pink and white calcite, dolomite, ankerite, and barite are also found, and gypsum is a common although not abundant constituent. Most of the veins are banded and several contain comb quartz. Parts of several veins consist of breccia cemented by vein minerals.

Veins consisting mainly of quartz have prominent outcrops and contain sulfides at the surface, whereas highgrade veins are thoroughly oxidized and have very inconspicuous outcrops. Vein outcrops are generally difficult and often impossible to recognize in natural exposures, and most of the unexplored veins can be seen clearly only in road cuts or along main trails.

History and Production

Historical data on Chilete are scarce; only two sources were available (1, 2). Veins of the Paredones area were discovered in the middle of the 17th century, and the oxidized ores were worked at that time for several years. After a serious cave-in on the West Pacasmayo vein, which trapped a considerable number of miners, the mines were abandoned. After a long period of inactivity the veins were reopened in 1856 and sulfide ores were mined more or less continuously until 1883, when transportation difficulties and lack of water for milling caused a shutdown. Most, if not all, of the production of the early years came from the Murcielago and West Pacasmayo veins. No data on total production are available.

The mine was leased by the Northern Peru Mining & Smelting Co. in 1924 and after 4 years of exploration was purchased outright for future development. In August 1951 construction of the present mill and camp began, and the mine came into production in May 1952. Monthly production has

increased from about 7,000 tons in the beginning to about 9,000 tons at present (1953).

Inasmuch as vein walls are generally clean and strong, ore is mined by shrinkage stoping. All broken ore is drawn on the 5th (lowest) level, either from stopes or from ore passes from the higher levels, and is transported on that level to the 250-ton flotation mill. Lead and zinc concentrates are trucked in one-ton steel containers to the railhead at Chilete, where they are loaded on flatcars for transportation to the port at Pacasmayo. For the period January 1 to August 30, 1953, lead concentrates averaged 60.36% Pb, 7.90% Zn, 1.73% Cu, and 56.87 oz. Ag per ton; and zinc concentrates contained 52.73% Zn, 1.26% Pb, 0.51% Cu, and 6.52 oz. Ag per ton.

Mineralogy

Vein minerals are listed below in order of abundance, and their occurrence is briefly described. No attempt was made to study the minerals of the oxidized zone.

Sphalerite is the most abundant sulfide mineral at Paredones. It occurs in all veins and in some parts of certain veins, particularly the Pacasmayo vein, it is the only abundant mineral. Three distinct types of sphalerite can be recognized: a moderate brown (5YR4/4 or 5YR3/4) "rosin" sphalerite giving a nearly white powder; a deep reddish brown type yielding a pale yellowish brown (10YR6/2) powder, and a purplish black variety giving a pale brown (5YR5/2) powder.

TABLE 1

ANALYSES OF SPHALERITE FROM CHILETE

	Color	Vein	Zn	Fe	Mol. %ZnS	Mol. %FeS	Sum
1.	Dark	West Pacasmayo, 5th level	56.25	9.56	83.9	15.1	99.0
2.	Dark	Murcielago, 5th level	47.65	9.21	71.1	14.5	85.6
3.	Medium	Murcielago, 3d level	57.50	6.28	85.8	9.9	95.7
4.	Medium	Pacasmayo, 1st level	61.40	4.39	91.7	6.9	98.6
5.	Medium	Murcielago, 4th level	59.20	4.32	88.4	6.8	95.2
6.	Light	West Pacasmayo, 5th level	63.65	1.67	95.0	2.6	97.6
7.	Light	Pacasmayo, 1st level	62.55	1.26	93.3	2.0	95.3

Seven hand-picked samples of sphalerite were analyzed for zinc and iron and the results are given in Table 1. Pure zinc sulfide contains 67.10% Zn and 32.90% S. Samples 1 and 6 come from the same locality, as do samples 4 and 7. All of the iron reported probably cannot be attributed to sphalerite as all the sphalerite at Chilete contains a small amount of chalcopyrite, but the amount to be deducted is very small. The major impurity is silica except in sample 2, which contains in addition 2.83% of galena. None of the sphalerites analyzed is the variety marmatite—10% or more Fe, according to Palache, Berman, and Frondel (4, p. 212)—although the dark type is close to marmatite. Where two varieties are found together, the lighter mineral is invariably the later.

Spectrographic determinations of Cd, Ga, Ge, and In were made on the same seven samples by Harry Bastron, of the U. S. Geological Survey. The results are given in the following table; a lone zero in the unit column means that the element was looked for but not detected.

In ores containing two types of sphalerite, cadmium is slightly more abundant in the lighter of the two types—1 (dark) and 6 (light), 4 (dark) and 7 (light)—but the differences are not large. The other spectrographic data are largely negative; the complete absence of germanium in all samples is notable.

	Cd	Ga	Ge	In
1.	0.36	0.0004	0	0.005
2.	0.23	0	0	0.002
3.	0.37	0.0005	0	0.009
4.	0.29	0	0	0.006
5.	0.42	0.0005	0	0.010
6.	0.39	0	0	0.005
7.	0.50	0	0	0.002

The sphalerite is ordinarily rather coarse grained; euhedral crystals up to 2 cm across and cleavage faces as much as 4 cm across are not uncommon. In general the sphalerite appears to contain only a little chalcopyrite as microscopic inclusions; however, chalcopyrite was found in all of the 19 polished sections studied.

Pyrite is ubiquitous at Chilete and occurs as thin layers in banded ore, as very fine grained veinlets cutting earlier sulfides, or impregnating wall rock fragments in breccia ore. Vein pyrite, where its habit could be recognized, is either pyritohedral or octahedral, whereas pyrite in walls or wall rock fragments is cubic.

Galena is found in all veins but may be present in only very small amounts locally. It is much finer-grained than the associated sphalerite, rarely showing cleavage faces as much as 1 cm across. Both coarse galena and the fine grained "steel" variety are found. In some veins, such as the Murcielago on the 3d level and the West Pacasmayo on the 1st level, galena appears to have been sheared during post-mineralization movement along the veins.

Megascopically visible chalcopyrite is scarce at Paredones and was seen only in the West Pacasmayo vein on the 1st level, the Esperanza vein on the 3d level, the Pacasmayo vein on the 4th level, and the "Valenciana" (Murcielago) vein on the 4th level. It is widespread, however, as microscopic inclusions in sphalerite from all veins. In general these inclusions are extremely small and become visible only at magnifications of 500 diameters or more.

Arsenopyrite was recognized in the field only in the West Pacasmayo vein on the 5th level, where it occurs as small rounded knots of minute acicular prisms or as tiny needles disseminated in quartz. It was recognized, however, as a minor constituent in polished sections of ores from all veins, although it seems to be rather rare in the Murcielago vein.

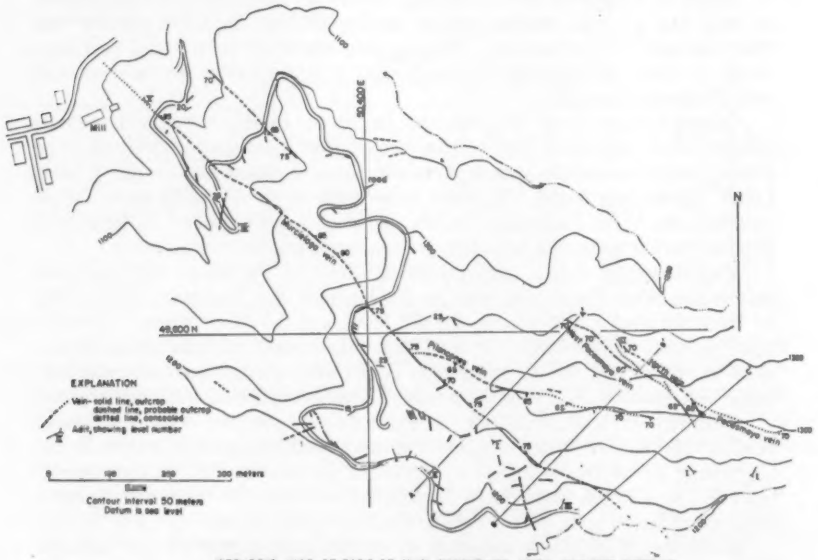
Marcasite (FeS_2) was identified in one polished section of ore from the West Pacasmayo vein on the 1st level. It forms ragged prisms replaced by sphalerite.

The only abundant gangue mineral is quartz; it is likely that more than 99 percent of the non-metallic vein minerals is quartz. It occurs as a fine-grained sugary groundmass, as comb quartz in the more prominently banded vein sections, and in vugs and late veinlets. It appears to have been deposited throughout the sequence of vein formation.

Small amounts of barite are found in vugs in the Pacasmayo vein and in a minor vein on the 5th level with pink calcite. Ankeritic dolomite occurs in veinlets cutting sphalerite and quartz in the Murcielago and Esperanza veins. Gypsum is widespread but not abundant. Most of it appears to be supergene, but gypsum in vugs in the Pacasmayo and Murcielago veins and in cores of quartz stringers in the Esperanza and "Valenciana" veins is probably hypogene. Sericite is a very minor constituent of several veins. It was identified only in thin section, in late veinlets with quartz, carbonate, and pyrite.

Structure of the Paredones Vein System

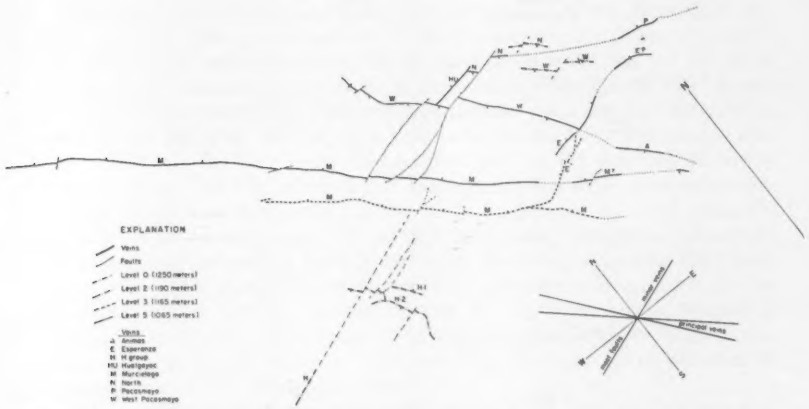
Vein outcrops in the Paredones area are shown on Figure 3, a generalized pattern of veins and faults is shown on Figure 4, and structure sections across the southeast corner of the area appear in Figure 5. Among the major veins, the Murcielago, West Pacasmayo, North, and Animas veins strike northwest and the Pacasmayo, Esperanza, Pilancones, and Hualgayoc veins strike within about 20° of east.



GEOLOGIC MAP OF PART OF THE PAREDONES AREA, CHILETE DISTRICT

FIG. 3.

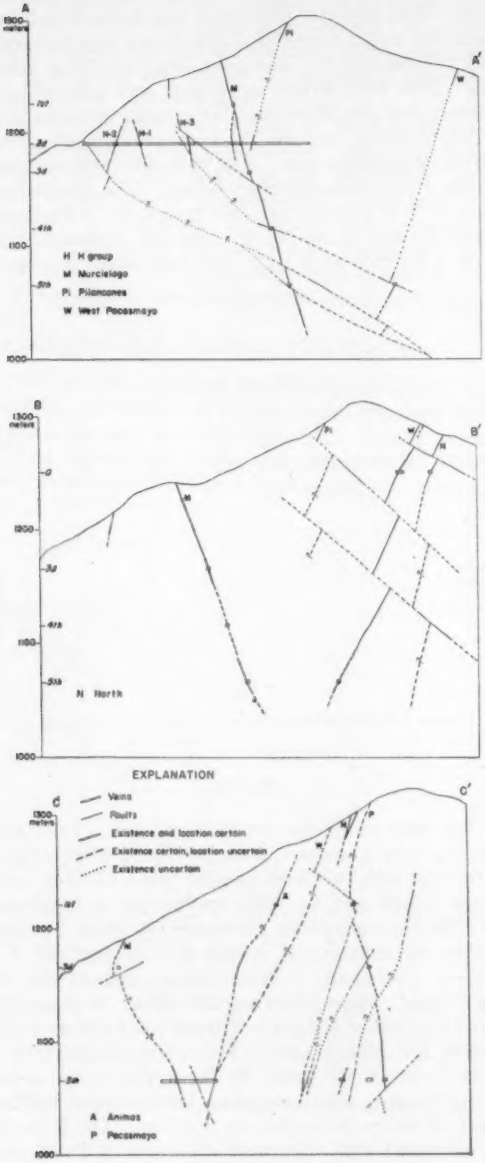
Major Veins.—The principal producing vein is the Murcielago, which has a known or inferred strike length of 1,700 m and has been explored over a length of about 1,000 m and to a maximum depth of 210 m below the outcrop along 6 levels. This vein strikes northwest and dips 65°–85° northeast. Near its southeast end the Murcielago vein splits into the Esperanza vein, which strikes east-northeast, and the "Valenciana" vein, which is the southeast continuation of the Murcielago vein. The only other vein to intersect the Murcielago vein is the Pilancones, described below. The Murcielago vein ranges in width from 1 to 4 m and averages perhaps 2 m. The Esperanza vein is known only underground on the 3d, 4th, and 5th (lowest) levels; its area of possible outcrop is covered with slide rock and talus. It dips steeply north



GENERALIZED STRUCTURAL PATTERN OF PRINCIPAL VEINS AND FAULTS ON FOUR LEVELS, PAREDONES AREA, CHILETE DISTRICT

FIG. 4.

in most places, but steep south dips are also recorded. The maximum known strike length of the vein is about 150 m, on the 3d level. On this level the vein splits to the east into two semi-parallel veins 40–55 m long; the north split ends against a fault and the south split seems to terminate against the Animas vein. The Esperanza vein intersects the West Pacasmayo vein on the 5th level, but the intersection is not well defined and it is uncertain whether the West Pacasmayo vein terminates against the Esperanza or whether the two veins cross without notable offset; it seems likely that the West Pacasmayo vein either ends or continues southeast as a barren fracture which may become the Animas vein. The corresponding intersection is not found on the 3d level; on this level the West Pacasmayo vein is a weakly mineralized strong fracture where is crosses the level, and the Esperanza vein appears to be cut off before it reaches the fracture. The Esperanza structure is rather weak compared with other vein structures at Paredones. The vein



STRUCTURE SECTIONS OF PAREDONES AREA
CHILETE DISTRICT

FIG. 5.

ranges in width from a thin stringer to 2.5 m and probably averages a meter or so.

The Pilancones vein splits off the Murcielago vein near coordinates 49,600N–50,400E on the surface, and can be traced along the outcrop for about 400 m east-southeast of the intersection. The intersection is not exposed either on the surface or on the Murcielago Zero (highest) level. The vein dips 65°–80° south. It has been recognized with certainty only on the surface and on the Zero level; apparently the rake of its intersection with the Murcielago vein is such that the vein does not appear in any working below the Zero level, unless the narrow vein cut 10 m northeast of the Murcielago vein on the 2d level is the Pilancones. The Pilancones vein in outcrop is about 3 m wide; at its only exposure underground it is 1.5 m across.

The West Pacasmayo vein strikes roughly parallel to the Murcielago and crops out about 200 m northeast of the southeast extremity of the latter vein. The vein can be traced for some 250 m along the outcrop and for 260 m on the 5th level. Inasmuch as the West Pacasmayo vein dips 60°–70° southwest, toward the Murcielago, the traces of the two veins are only about 90 m apart on the 5th level, which here is 200 m below the West Pacasmayo outcrop. The vein has been recognized on the Zero, 1st, 3d, 4th, and 5th levels. It ranges from 1 to 3 m in width and averages slightly more than one meter.

The North vein lies parallel to the West Pacasmayo vein and crops out about 20 m to the northeast. It can be traced clearly along the outcrop for 150 m and may extend for another 150 m to the east-southeast as the Pacasmayo vein. The North vein is known with certainty underground only on the Zero level; it probably appears also on the 5th level, where, because of its slightly steeper dip, it lies some 20 m farther northeast of the West Pacasmayo vein than at the outcrop. The vein is as much as 1.5 m wide but its average width is only about one meter.

The outcrop of the Pacasmayo vein lies along the southeast extension of the North vein, but the exact relationship of the two veins cannot be determined because of lack of exposures. An open cut 100 m long marks the former outcrop of the vein. The Pacasmayo vein strikes east-southeast to east and dips 70° south at the outcrop, 70°–85° north on the 1st and 3d levels, and more or less vertically on the 5th level. Maximum known strike length is 200 m, on the 1st level. Clarification of the relation between the Pacasmayo and North veins on the 5th level awaits further development, but it seems likely that the two veins will prove to be one and the same. The Pacasmayo vein attains a maximum width of 3.5 m and has an average width of perhaps 1.5 m or slightly more.

The Animas vein strikes northwest and dips 65°–80° southwest. It lies about 30 m southwest of the West Pacasmayo vein at the surface. Its maximum known strike length, on the 1st and 5th levels, is about 80 m, and the limits of the vein probably have been reached. The vein appears to cross the north branch of the Esperanza vein on the 3d level without offset and to cut off the south branch. No other veins are known to intersect the Animas vein unless the Animas and West Pacasmayo veins join on the 5th level.

Although the Animas structure is fairly strong in places, the vein is generally rather thin; it averages less than one meter in width.

The Hualgayoc vein is found only on the 5th level, where it forms a crossing between the West Pacasmayo vein and the presumed North vein. The vein strikes slightly north of east and dips 50°–75° north. It has a strike length of about 45 m. To the west it appears to terminate against the West Pacasmayo vein, and eastward it passes into a single fracture on approaching the North(?) vein. The Hualgayoc vein cannot be correlated with any other vein at Paredones either on the surface or underground. It has a maximum width of 1.5 m and an average width of about one meter.

Faults.—Veins at Paredones are cut by a large number of post-mineral faults. The principal faults strike east-northeast and dip northwest (Fig. 4), although in the eastern section of the mine a few faults strike north to northwest and dip steeply west. Some if not all of the faults have a marked strike-slip component of movement, as along several faults, veins which dip toward each other are offset in the same sense (Fig. 5, sec. AA'). In general the southeast side moved northeast relative to the northwest side; this regularity of displacement is well shown in Figure 5, where the vein offsets simulate those ascribable to reverse faulting. Maximum strike-slip displacement is about 18 m, but most veins are displaced less than 5 m.

Post-mineral Movement Along Veins.—Very little evidence of post-mineral movement along veins was found. Striations in the hanging wall of the Murcielago vein on the 3d level near coordinate 10,650E plunge 10°–15° northwest and on the 5th level near coordinate 10,400E plunge 25° northwest.

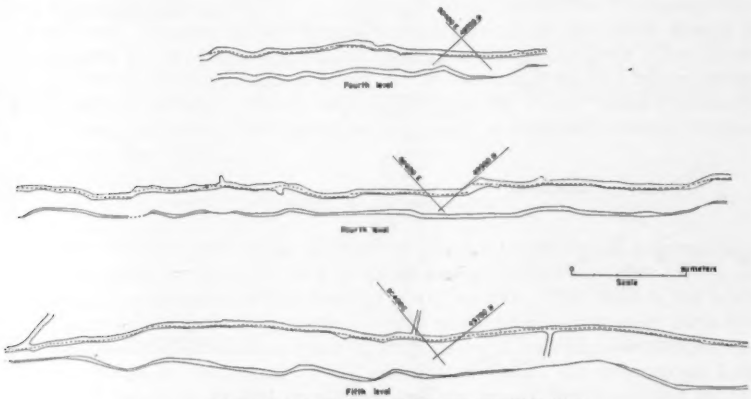
Most of the minor splits in the hanging wall of the Murcielago vein strike 10°–30° W and dip steeply east (the acute angle of their intersections with the vein opens to the northwest); they are mineralized gash fractures opened during the movement postulated in the following section. Minor splits in the footwall of the vein are less regular, and some whose acute angle of intersection opens to the northwest may have been opened by a reversal of movement during mineralization.

Minor splits off the West Pacasmayo vein are mostly in the hanging wall, and they have a more westerly strike than the vein, suggesting that at least some of the movement along the parent fracture during mineralization was in a sense opposite to that along the Murcielago vein.

Localization of Ore

Veins.—The only vein that has been developed and mined sufficiently to offer much evidence on ore localization is the Murcielago. On the 5th level the vein consists of two large ore shoots 55 and 90 m long respectively and a small shoot 25 m long, separated longitudinally by barren vein sections 10 to 15 m long. Only the two large shoots are found on the 4th level, which begins southeast of the small shoot. Within the shoots the vein varies somewhat in width, depending on the strike; the thicker parts of the vein tend to occur where the strike swings slightly to the north. Barren sections generally begin where the vein swings to a more easterly strike and end at or near

a slight bend to the north. These relations of vein width to strike are shown schematically on Figure 6. In this figure the changes in strike are greatly exaggerated for clarification and emphasis, as actually they are extremely subtle, mostly less than 5°, and although they can be recognized readily enough in the field, they could not be illustrated clearly without some exaggeration. These variations in width indicate that the southwest side of the original fracture moved northwest relative to the northeast side before or during deposition of vein minerals. At the present stage of development of the vein, data are inadequate to show whether this movement had any vertical component.



VARIATION IN WIDTH OF MURCIELAGO VEIN WITH CHANGES IN STRIKE

FIG. 6. In each group of drawings, the upper plan is of the level with the footwall of the vein shown as a dashed line; the lower plan shows vein widths according to sample maps with bends exaggerated for clarification.

Vein intersections.—Vein intersections at Paredones are exceptions to the well-established generalization that such intersections should be favorable loci for ore deposition. Although several intersections have been found, no ore shoots or even increases in vein width are associated with them; indeed, at several intersections the veins are leaner or thinner or both than at some distance away. Figure 7 presents quantitative data on the lead and zinc content of several veins at and near intersections. The combined lead and zinc content taken from company assay maps and recomputed to one-meter width is shown as ordinates; distances from intersections are shown in meters as abscissae. The curves therefore show the relative total lead and zinc content at any given distance from the intersection.

The various vein intersections and their characteristics are listed below:

Zero level—Murcielago and Pilancones veins: intersection inaccessible but apparently no significant change in either vein; Pilancones vein may pinch out near intersection.

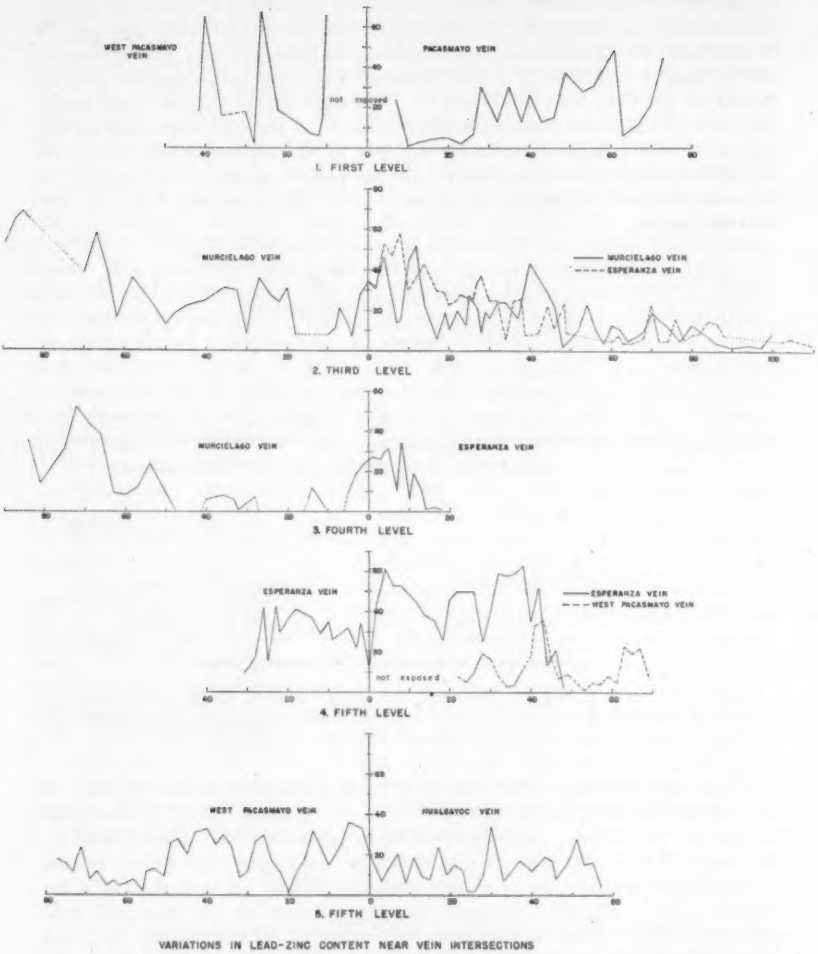


FIG. 7. Ordinates—Percent of combined lead and zinc, recomputed to 1 m width. Abscissae—distance from intersection (0) in meters.

First level—Pacasmayo and North veins: intersection not recognized, may be a minor barren fracture. Pacasmayo and West Pacasmayo veins: intersection not exposed but both veins are reduced to a series of thin veinlets as the intersection is approached (Fig. 7–1).

Third level—Murcielago and Esperanza veins: intersection poorly defined, but no noticeable change in Murcielago vein after Esperanza splits off to east-northeast. Both veins die out to southeast and northeast respectively beyond intersection (see Fig. 7–2). Esperanza and Animas veins: no assay data available, intersection poorly defined and metal content appears to diminish near intersection.

Fourth level—Murcielago and Esperanza veins: intersection very poorly defined, both veins weak where Esperanza vein splits off to east-northeast (see Fig. 7–3).

Fifth level—Murcielago and Esperanza veins: no intersection on this level, as Esperanza vein appears to terminate 25–35 meters before Murcielago vein is reached. Esperanza and West Pacasmayo veins: no noticeable change in Esperanza vein at either side of intersection; workings along the West Pacasmayo vein end about 18 meters before the intersection is reached but no change is evident as the intersection is approached (see Fig. 7–4). West Pacasmayo and Hualgayoc veins: intersection well exposed, no noticeable change in either vein (see Fig. 7–5).

Wall Rock Alteration

The country rock of the mineralized area at Paredones is a monotonous body of greenish gray to dark greenish gray porphyritic rocks. Only the occasional occurrence of flow breccias gives any clue in the field to the origin of the rocks; in general any flow layering, variation in composition from flow to flow, interbedded tuffs or other characteristics of volcanic assemblages have been effectively obliterated during alteration. Under the microscope, however, all the rocks studied show fairly well preserved flow structures and the typical hyalopilitic or trachytic groundmasses of andesitic volcanic rocks. Wall rocks from four localities along three veins were examined in thin section. At each locality two or three specimens were collected at various distances from the vein walls. A total of 11 sections was studied. All the rocks present certain alteration features in common.

Feldspar phenocrysts invariably are sericitized, the intensity of sericitization increasing somewhat as the vein is approached. Most feldspars are also altered to calcite, but this alteration decreases in intensity with nearness to veins at three of the four localities. The sequence of feldspar alteration is not clear, but the reciprocal variation in intensity suggests that sericitization may be later than and superimposed on calcitization. Epidote, chlorite, and iron oxide replace feldspar in very minor amounts. In all but one thin section the feldspar remnants are albite and the original composition is unknown; unaltered feldspar phenocrysts in the very few fresh rocks found at Chilete are andesine or andesine-labradorite.

Dark silicates are completely altered to a very fine grained aggregate of pale green chlorite (antigorite), commonly accompanied by varying amounts of calcite, iron ore, quartz, sericite, leucoxene, and reddish iron oxides. A common alteration is to pseudomorphs composed of a mesh of chlorite with interstitial quartz or sericite, which simulate the common mesh serpentine

alteration of olivine. Another widespread alteration is to pseudomorphs of chlorite cut by a triangular or irregular reticulated network of leucoxene or iron ore. The original minerals are unknown; shapes of some pseudomorphs suggest hypersthene and of others suggest biotite (although biotite is extremely rare in the fresher rocks), but in many examples alteration has extended beyond the original crystal boundaries and even the shape of the replaced grain gives no clue to its identity.

The groundmass of all the rocks consists of dusty plagioclase microlites and iron oxide granules in a nearly isotropic matrix that is in part chlorite. Microphenocrysts of feldspar are sericitized but not as completely as the accompanying phenocrysts. Irregular scattered patches of quartz, chlorite, and calcite are common; quartz becomes more abundant near the vein in three localities. All the rocks are pyritized, but only at one locality did the amount of pyrite increase near a vein; elsewhere pyritization seems to have affected the country rock more or less uniformly. The pyrite is largely if not entirely cubic in habit.

In wall rocks of the Pacasmayo vein (1st level) and the West Pacasmayo vein (5th level) small amounts of a mineral believed to be adularia are associated with quartz. The adularia occurs as tiny euhedral crystals, commonly rhomb-shaped, around the edges of quartz patches. In one section the adularia was found with irregular amygdule-like bodies as a thin layer between a rim of chlorite and a core of quartz; in another it forms a crust between quartz and wall rock. The crystals are so minute as to preclude any precise optical measurements, even with the use of an oil-immersion objective, but the negative optical sign, birefringence of about 0.006, marked negative relief, and particularly the rhombic cross-sections, suggest adularia.

Internal Vein Structures

Veins at Paredones were formed by a variety of processes, including fissure filling, breccia filling, and replacement. The most abundant ore type is a banded rock consisting of subparallel veinlets of sulfide minerals ribbing and replacing country rock or of a series of crustified quartz-sulfide veins; these

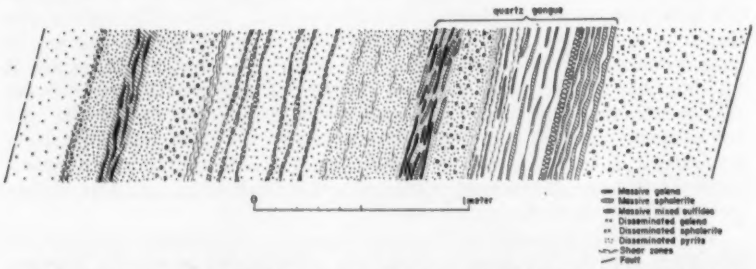
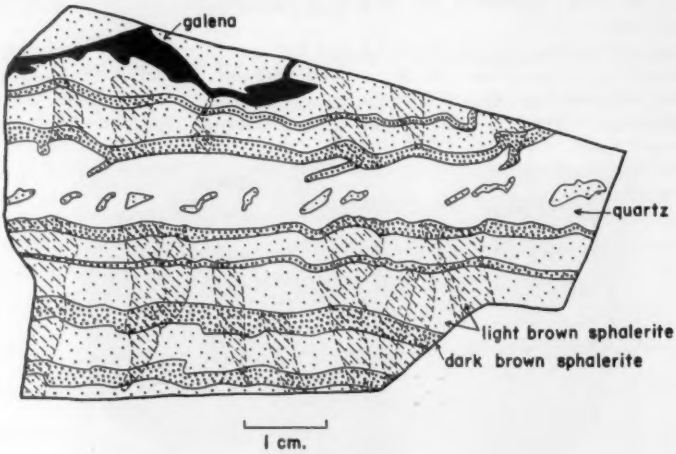


FIG. 8. Section of Murcielago vein, I-4 stope, looking SE. The footwall is marked by gouge and slickensides; the hanging wall is only slightly faulted. Quartz gangue is abundant only in the place indicated; elsewhere the sulfide minerals are either vein or are disseminated in silicified country rock.

two subtypes commonly occur together. Breccia ore is found locally, particularly in the Pacasmayo vein near the east end of the 3d level and in the Murcielago vein near the northwest end of the same level. A few examples of ore types are illustrated in Figures 8 to 10.



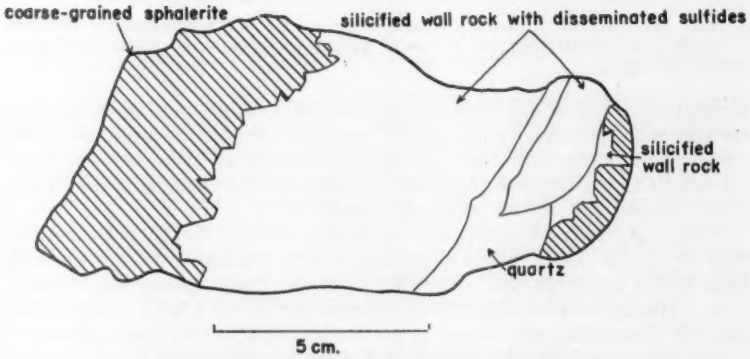


FIG. 9. Upper: Banded sphalerite from Murcielago vein, 3rd level. Cross-hatched areas are individual crystals of sphalerite that cross compositional layers, suggesting that they crystallized from an original colloidal state. Lower: Coarse-grained sphalerite from West Pacasmayo vein, 5th level. Silicified country rock is replaced by sphalerite in large euhedral crystals.

Figure 8 is a section of the Murcielago vein in the I–4 stope above the 4th level. The vein at this place was about 3.2 m wide. The banding, although irregular in detail, is very regular if the entire vein is considered. Such banding is typical, particularly of the Murcielago vein. Quartz is a prominent gangue mineral in a section 30 cm thick near the right (southwest) side of the vein; elsewhere the gangue is silicified and pyritized andesite country rock.

Figure 9 (upper) is a sketch of a sawed but unpolished face of a specimen of banded sphalerite from the Murcielago vein on the 3d level, showing rhythmic symmetrical deposition of the light brown and medium brown types of sphalerite. Galena is clearly later than sphalerite. Each of the cross-

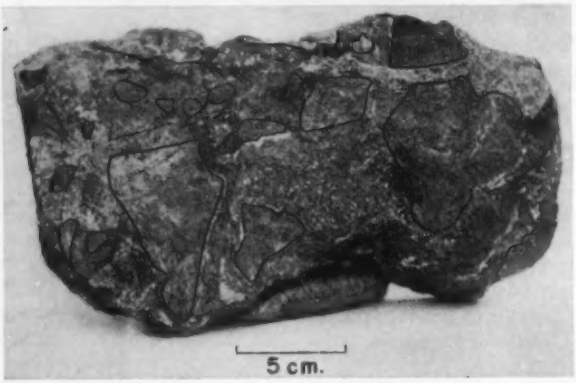


FIG. 10. Breccia ore from Pacasmayo yein. Breccia fragments are outlined in black. Interstitial material is mostly galena with scattered quartz-lined vugs (white patches).

hatched areas within the sphalerite shows a uniform orientation of cleavage surfaces and represents a single crystal unit; inasmuch as the units are rather irregular and cross more than one compositional layer, it seems likely that the sphalerite was deposited originally in open space as colloidal layers of different composition, and subsequently crystallized.

Figure 9 (lower) is a sketch of sphalerite ore from the West Pacasmayo vein on the 5th level. Silicified country rock is replaced by coarse-grained light brown sphalerite that shows sharp crystal faces against the replaced rock. The light brown sphalerite contains no pyrite and grades outward into purplish black sphalerite veined by pyrite; the light variety seems therefore to have been deposited later than the dark. Galena occurs only in the silicified wall rock, and its age relationship to sphalerite is unknown.

Figure 10 is a photograph of breccia ore from the Pacasmayo vein near the east end of the 3d level. Wall rock fragments are outlined in black. The interstitial material is largely galena with a few small quartz-lined vugs (white patches). Several breccia fragments are rimmed by a thin layer of

comb quartz and locally the galena is interlayered with quartz. All the fragments are strongly pyritized. The fragments appear to have been rounded somewhat by replacement, but the high proportion of fragments to sulfide minerals (the proportion is much greater in general than in the specimen shown, which was selected as an example of high-grade breccia ore) indicates that little replacement has taken place.

Sequence of Deposition of Vein Minerals

No single well-defined sequence of deposition can be established for the vein minerals at Chilete, as in general several separate sequences are evident at almost any place in the veins. However, for any given single sequence, the following observations are applicable. Quartz was probably the earliest vein mineral to be deposited, as it is veined and replaced by early sulfide minerals. It was deposited throughout the period of mineralization and occurs finally in veinlets cutting sulfides, and in vugs. Pyrite was also deposited throughout the sequence but seems to have been formed for the most part at

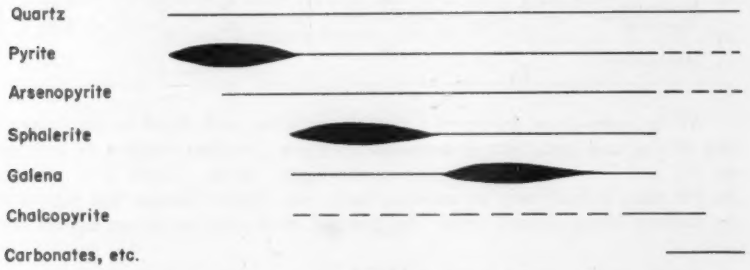


FIG. 11. Diagram showing generalized age relationships of vein minerals.

an early stage, as it is most abundant as euhedral or slightly corroded crystals embedded in sphalerite and galena. Arsenopyrite occurs both as early euhedral grains in sphalerite and galena and in late veinlets and vugs. Sphalerite and galena were deposited during the same general period, but sphalerite is generally earlier and is veined by galena. Chalcopyrite occurs in veins cutting both sphalerite and galena, but the very fine grained chalcopyrite disseminated in sphalerite may have been formed by exsolution from the sphalerite. The minor gangue minerals are all late and are found mainly in vugs. Age relationships of the various minerals are summarized in Figure 11.

Variation in Mineralization with Depth

The total combined lead-zinc content of four major veins (Murcielago, Pacasmayo, West Pacasmayo, and Esperanza) does not seem to vary systematically with depth; indeed each of these veins has roughly the same combined metal content throughout its known vertical extent, and furthermore all of them have nearly the same combined percentage of lead and zinc.

TABLE 2

ZN/PB RATIO IN INDIVIDUAL VEINS AT VARIOUS LEVELS

Vein	Level	No. of assays	Zn/Pb ratio
Murcielago	2	29	2.60
Murcielago	3	137	2.31
Murcielago	4 (NW oreshoot)	85	2.64 } 2.54
Murcielago	4 (SE oreshoot)	177	2.50 }
Murcielago	5 (NW oreshoot)	72	3.91 } 4.38
Murcielago	5 (SE oreshoot)	137	4.62 }
Pacasmayo	1	75	1.83
Pacasmayo	3	203	2.25
Pacasmayo	4	151	8.25
Pacasmayo	5	40	9.44
West Pacasmayo	1	23	1.85
West Pacasmayo	3	160	1.59
West Pacasmayo	4	180	3.09
West Pacasmayo	5	104	4.32
Esperanza	3	43	1.65
Experanza	4	93	5.03
Esperanza	5	91	4.16
Hualgayoc	5	38	3.26

All the veins show, however, a notable variation with depth in the proportion of zinc and lead; zinc is considerably more abundant relative to lead on the 4th and 5th levels than on any of the higher levels. Table 2 shows the Zn/Pb ratio in each vein at various levels, and Table 3 shows this ratio for the various veins at each level. In general, each vein shows an abrupt in-

TABLE 3

ZN/PB RATIO AT EACH LEVEL FOR VARIOUS VEINS

Level	Vein	Zn/Pb ratio
1	Pacasmayo	1.83
	West Pacasmayo	1.85
2	Murcielago	2.60
3	Murcielago	2.31
	Pacasmayo	1.45
	West Pacasmayo	1.59
	Esperanza	1.65
4	Murcielago	2.54
	Pacasmayo	8.25
	West Pacasmayo	3.09
	Esperanza	5.03
5	Murcielago	4.38
	Pacasmayo	9.44
	West Pacasmayo	4.32
	Esperanza	4.16
	Hualgayoc	3.26

crease in the Zn/Pb ratio between the 4th level and the next higher level (Table 2); this increase takes place in the Murcielago vein between the 5th and 4th levels. At a given level all veins, except the Pacasmayo vein on the 4th and 5th levels and the Esperanza vein on the 4th level, have roughly similar Zn/Pb ratios (Table 3). No vertical variation in types of sphalerite or in minor mineral content was detected, except that arsenopyrite appears to be more abundant on the 5th level than elsewhere. The uniformity of variation in the several veins and their very similar total lead-zinc content suggest that all the veins were formed during a single period of mineralization.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
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BIOGEOCHEMICAL PROSPECTING AT THE SHAWANGUNK MINE—A CASE STUDY

JOSEPH E. WORTHINGTON

ABSTRACT

During the spring of 1954 a preliminary biogeochemical study was made of the Shawangunk Mine of Wurtsboro, New York. This is a fissure vein type of lead-zinc deposit containing minor amounts of copper. Copper and zinc were determined in common white birch twigs by a modification of the method of H. V. Warren. In addition lead was determined by modifying a technique of E. B. Sandell. The separations and analyses were carried out in the Chemistry Laboratory of Columbia University using a Lumetron Photoelectric Colorimeter for final determination of the metallic ions.

Results were calculated and tabulated for parts per million of copper, zinc and lead, and copper-zinc ratio. The lead and copper-zinc ratio values, to a greater extent than the copper and zinc values, showed encouraging results in defining the ore body as to content and possible shape.

INTRODUCTION

THIS investigation was carried out to test the effectiveness of biogeochemical analyses in exploring for bodies of lead and zinc ore known to crop out in an area of moderate rainfall and temperature. To the writer's knowledge few such case histories are available in print. It is hoped that this instance will be of value as one concrete example.

For the most part the analytical procedure used was that already in general practice; only those techniques especially developed during the present investigation are therefore described.

The author wishes especially to acknowledge his gratitude to all those at Columbia University who have been of assistance during these studies—in particular, Prof. T. Ivan Taylor of the Department of Chemistry as to problems of analytical procedure; R. A. Barker, Graduate Assistant in Economic Geology, of the Department of Geology, and Mrs. Barker in advising on biogeochemical topics; and, for general counsel and encouragement, Prof. Chas. H. Behre, Jr., of the Department of Geology. Research funds of the Ore Genesis Laboratory, Columbia University, were made available for these studies.

GEOLOGY OF THE LOCALITY

The Shawangunk Mine near Wurtsboro, New York, was chosen as one especially well suited to the present investigations. Since the biochemistry of zinc is perhaps the best known of the elements sought by biogeochemical investigation, it was decided to select for testing a deposit that contained appreciable amounts of zinc.

This area had been described by Ingham (2) and more recently by Gray (1). Its selection followed careful consideration and rejection of four other localities even though these latter were all about equally accessible to the author, and all are noted for their zinc occurrences—Friedensville, Pa., Franklin, N. J., some small prospects in the Connecticut Valley, and Phoenixville, Pa. Reasons for rejecting these areas illustrate the problems involved. The first two were not used because both are old mining camps with surface redistribution of metallic ions by development of dumps, mills, and the like. Information as to the ore distribution was inadequate in the Connecticut Valley locality and suburban housing had much disturbed the surface at the populated town of Phoenixville.

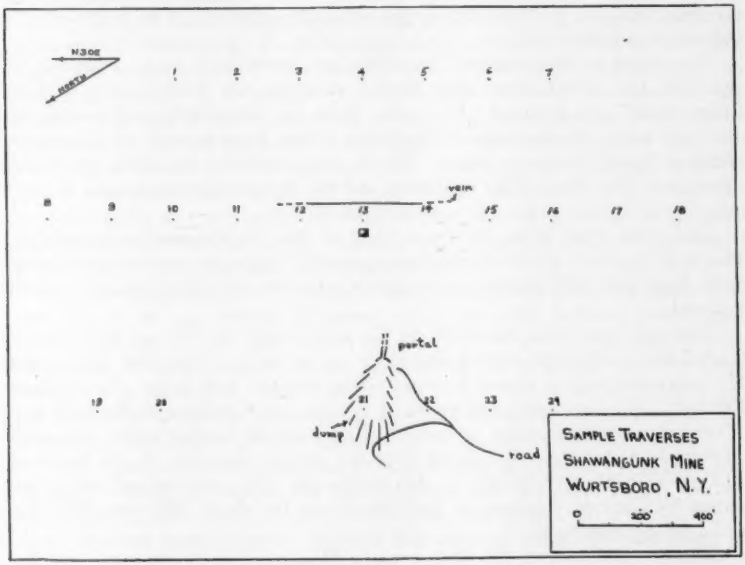

FIG. 1.

The portal of the Shawangunk Mine is on Shawangunk Mountain. This mine was chosen because it is in a position as inaccessible to the possible contamination attendant on nearness to a highly industrialized metropolitan area, and because copper, zinc and lead are found there in fairly strong concentrations. In addition, the work of Dr. Carlyle Gray on the mining district (from which the following summary is taken) was available and provided an excellent guide in determining areas favorable for sampling.

The Shawangunk Mine is easily visible from U. S. Highway 209, a mile south of Wurtsboro near the point where Route U. S. 209 intersects N. Y. Highway 17. Shawangunk Mountain, parallel to U. S. 209 and about one

mile to the southeast over most of the distance from Port Jervis, New York, to Wurtsboro, presents an unbroken expanse of trees. The mine dump is easily visible several miles away. A secondary road leads directly to the mine from a point on the highway approximately 1.2 miles north of Wurtsboro. The mine road is about a mile and a half long, but is passable to an ordinary passenger car only where the road is on the valley floor. The general topography of the region and the mine road are shown on the AMS-1 Wurtsboro, New York Quadrangle (7.5 minute series, scale 1:31,680), but the mine opening is omitted from the map.

The structure of Shawangunk Mountain is essentially a monocline striking approximately N 35° E and dipping from 25° to 50° NW in the vicinity of the Shawangunk Mine. Because of the monoclinal dip the mountain itself is asymmetrical, the southeastern slopes being the steeper. The northwestern slope averages about 13°.

The rocks of Shawangunk Mountain are exclusively early Paleozoic in age. On the southeastern slope of the mountain the Ordovician "Hudson River shales" are exposed. Overlying these unconformably and making up the main mass of Shawangunk Mountain is the Shawangunk conglomerate, which is basal Silurian. Above this on the northwestern slope are found successively the High Falls formation and the Binnewater sandstone, in conformable relationship and likewise Silurian in age.

The mine itself is in the upper part of the Shawangunk conglomerate. This unit here is a silicious sandstone, generally light in color, conglomeratic in its basal part and arkosic in its higher members, in which the ore deposit is found.

The ore deposit, as described by Gray, is of the fissure vein type and is located on a fault parallel with the strike of the beds. This fault dips about 45° northwest and is shown by Gray to be reverse, with a dip slip of about 200 feet. The mineralization exists in breccia zones related to the fault and in vein segments that occur *en echelon* to the fault in the foot wall. The vein segment is flatter than that of the fault but steeper than that of the bedding, dipping probably 35° to 40° to the northwest. The mineralized zones are shown by Gray to continue in both directions for about 800 feet along the strike of the mountain.

The ore minerals of the Shawangunk Mine are simple primary sulfides. The principal mineral is sphalerite with subordinate galena. Chalcopyrite is present in lesser amounts, in addition to pyrite, which is found disseminated in the country rock, and a small amount of native gold. The only gangue mineral of importance is quartz. The secondary minerals which would be expected with such an association are also present; anglesite, chalcocite, covellite, malachite, azurite, and limonite. The grade of ore in this mine varies through the following limits, as listed in the report by Gray:

zinc	3.91% to 10.00%
lead	0.47 to 5.5
copper	trace to 1.18

Gold and silver are reported to be present only in traces.

An important aspect to be considered in this sort of investigation is the thickness and character of soil cover. This problem is greatly complicated in the northeastern United States by glacial deposits. The exact nature and thickness of soil cover is especially difficult to determine in an area such as this and would require detailed study, quite beyond the range of this investigation. A small amount of general information is available and so crude approximations may be made.

In the mineralized area the silicious bedrock of the Shawangunk conglomerate does not readily weather into thick soils. Casual observations in the woods of Shawangunk Mountain reveal relatively large amounts of humus, but the soil cover is mostly thin, as outcrops are fairly common, particularly at the higher elevations.

For at least three reasons these conditions would not seem to favor biogeochemical prospecting, which depends on an ore body having an aureole of abnormal concentration of its metallic ions, which might therefore be extracted from the soil by trees. In the first place, the vein is a relatively thin tabular body and should be expected to have a different and probably smaller halo than that of a large disseminated deposit, which would be the ideal type for biogeochemical prospecting methods. Secondly, the bedrock weathers slowly and accordingly might not carry weathered vein material to the surface as rapidly as many other lithologic types. Thirdly, the soil cover, being thin and of questionable origin, would be much less favorable to this type of exploration than a deep mantle of residual soil.

In one way, however, the geologic conditions should favor the discovery of this deposit by biogeochemical means. Since the vein, bedding, and slope of the hill all dip in the same direction, the halo of anomolous concentration should be sharply defined. Thus prospecting for a deposit of this nature should be a relatively simple matter. A single line of samples taken perpendicular to structure (that is, up the hill) should show a sharp drop in concentration a short distance up slope from the outcrop of the vein.

This concept greatly simplified the sampling procedure in the present case. A single line of samples at 200 foot intervals was run close to the vein outcrop and parallel to it. A second line was run about 450 feet up the hill from this and parallel to it. A third line was run about 600 feet below the vein and this line cut directly across the large dump. These lines then might each be expected to show a fairly constant character, perhaps declining in value toward their extremities. The highest should yield the lowest metal content and should provide a measure of the background values; the middle line over the vein should show higher values; and the lowest line should either be the highest in trace element concentration or should decline into "background" values again if the halo of the vein does not extend that far.

SAMPLING

It is common knowledge that plants use varying amounts of different ions in their growth processes. The identities, role, and relative amounts of these elements vary widely for many different sets of conditions. Species, organ,

time of year and location all play a part in determining what elements will be present and their relative concentrations. Such elements as boron, zinc, manganese, and copper are mentioned in this group by Stiles as being frequently present in trace amounts. He suggests that the role of copper and zinc is in regulating oxidation-reduction potential as catalytic agents. The role of the third element, lead, is much less well understood.

The relative abundance of these three elements varies with the conditions mentioned above. In order to keep the conditions of occurrence in plants constant throughout the investigations, the following limiting factors were introduced.

The sampling was restricted to one species, the common white birch, *Betula populifolia*. It was originally intended to sample only specimens with trunk diameters of one to three inches, but their scarcity necessitated using much smaller specimens also. The age of the specimen should not be a particularly critical factor, according to Warren and Delavault (7). In selecting the organ to be sampled the work of Warren (6, 7) was taken as a guide. Twigs were taken of about pencil size, one-eighth to one-fourth inch in diameter in all cases. The time of year was also eliminated as a possible variable factor by doing all the sampling on one day. Thus the major variable factor was the position of each tree sampled, in regard to the position of the known ore body.

Reference to any of the works of Warren (6, 7) on copper and zinc prospecting gives an estimate of values which may be expected in this area. Background values for copper in white birch trees should run on the order of 10 parts per million of the twig and for zinc should be on the order of 100 parts per million. Possible values for lead are much less well known; however, a suggested approximation is one part per million.

The collection of samples presented difficulties of its own, most of which were solved fairly readily. The most obvious concern was to pick a tree readily available all over the area to be prospected. In this case white birch was selected with more regard to the available data on trace elements in birch trees than to its actual preponderance over this deposit. Thus, although the species was plentiful higher on the mountain, on the lower slopes samples had to be taken where they could be found with the resulting gaps that may be seen in the accompanying sketch map. In this particular locality some species of oak, probably one of the scrub varieties, would have afforded much better coverage; however, in view of the readily available data on birch trees, and the fact that birch trees are common in many parts of the United States and thus would be more widely representative in this as a test case, it was decided to use them rather than other vegetation.

The sampling was carried out in a single day on similar parts of the tree —stems of pencil size. The samples were collected on March 16, 1954, early in the spring, well before the sap started to flow. Twigs were cut with a pair of steel pruning shears; hence no copper or zinc plating was present to contaminate the sample. The samples were stored in ordinary paper bags until they were analyzed.

PREPARATION OF SAMPLES

The ashing of the samples was carried out in a muffle furnace. The samples were first charred in a few milliliters of concentrated nitric acid, approximately 1 ml per gram of sample. This was added in small increments to prevent frothing. The samples were then heated over a Bunsen burner flame until the oxides of nitrogen were driven off. Following this, the samples were placed in a cool muffle furnace and the temperature gradually raised to about 600° C. After several hours at this temperature the ash becomes reduced to a very light gray powder without any remaining carbon. This was then dissolved in about five milliliters of 3N hydrochloric acid. The acid was then slowly evaporated in order to bring the residue into a more easily soluble form and to destroy oxidizing compounds. This dry residue was next dissolved in .01N hydrochloric acid. The solution was then diluted to a known volume in order to begin the metal separations.

This step took more time than any other, several hours being required for a group of samples to ash and cool.

CHEMICAL CONSIDERATIONS

Once the sample has been collected and ashed, there are many methods that might be used in the measurement of trace amounts of copper, zinc, and lead in plant tissues. Since a slight acquaintance with the work of Warren, Delavault, and associates (6, 7) in biogeochemical prospecting in Canada provided the impetus for this investigation, their analytical procedures were used as models for this work. These methods have been developed mainly for detecting copper and zinc, quite possibly on the theory that ore deposits of other metals generally carry enough of either one or the other of these two metals to be detected by biogeochemical means. In this case the ore body to be tested was principally a lead-zinc ore with lesser amounts of copper. Therefore it was decided to analyze for copper and zinc and to include determinations for lead in order to see whether or not this metal might also be found in anomalous concentrations in plant life over deposits.

Another departure from the procedure of Warren et al. was the use of a photoelectric colorimeter in analyzing the samples, whereas Warren and his associates suggest a titration method. In this case the mechanical method was selected because the technique developed in this investigation was not originally intended for use in the field. In addition, the possibility of encountering very small quantities of lead made the greater sensitivity of the photoelectric cell seem desirable. In most other operations the procedure used here followed that of Warren and his associates very closely.

METHOD OF ANALYSIS

After the required solutions were made and purified, the actual separations of the ions under investigation are carried out simply. After the samples had been cut and brought in from the field, the entire procedure took two days in the laboratory. However, this estimate is actually misleading as most of the

time was actually spent waiting for the sample to ash and cool as previously explained.

The reagent used in separation of all three metallic ions in this investigation was diphenylthiocarbazone, more commonly known as dithizone. With many metal ions this forms brilliantly colored metal-dithizonates when the two are brought into contact. Dithizone is soluble in most organic solvents, e.g., acetone, carbon tetrachloride, and chloroform; carbon tetrachloride was used exclusively in these separations. Since carbon tetrachloride is immiscible with water, the metallic ions do not readily combine with the dithizone unless the two phases are shaken together in a separatory funnel for a minute to allow the metallic ion to combine with the dithizone in the carbon tetrachloride phase. The concentration of the metal dithizonate may then be determined photoelectrically.

The size of the sample to be taken for analysis depends on the sensitivity of the method of measurement. For this case one-gram samples were found to be a convenient size. The separations were carried out by extracting the solution containing the metallic ions into carbon tetrachloride. The carbon tetrachloride phase in each case was kept in a screw top test tube, so that all the samples might be later analyzed at the same time. The solutions could be kept successfully in this manner for periods extending up to three days.

Warren used a titration method in which known amounts of either more dithizone or metal solution were added until the neutral gray end point is reached. Instead of this procedure, the metal concentrations were estimated by transmission measurements with a Lumetron photoelectric colorimeter.

The operation of this instrument is simple. After proper adjustments and standardization, a sample may be analyzed by one dial setting. Standardization requires only three steps—selection of primary filter, proper lamp intensity, and proper reduction plates, followed by measurements on samples of known concentrations. A filter is selected such that it will provide nearly monochromatic light from the tungsten bulb light source, so that Beer's Law will be satisfied. The selection is made from published absorption spectra. In the case here described, in order to follow Sandell (4) as closely as possible, copper and zinc were determined at 515 millimicrons. The choice of reduction plates and lamp intensity are trial and error mechanical manipulations of the apparatus, which merely serve to bring the variation of the sample into the range of the slide wire. Before each series of measurements a blank sample (a determination in which the "unknown" is distilled water) was placed in the instrument and with the slide wire set at 100 the light to the balance photo cell was adjusted until no current flowed through the galvanometer. Readings on the samples then gave the percent transmission directly.

A problem arises in connection with the dithizone solution. Sandell (4) recommends the relatively low concentration of dithizone of 0.001 percent. A few preliminary standardization curves were made using this concentration, which gave excellent results. However, the stoichiometric relation between the metallic ions and the dithizone molecule must be taken into account,

$$\text{(Cu, Pb, or Zn) Me} + 2\text{Dz} = \text{MeDz}_2$$

and it becomes evident that quite large volumes of .001 percent dithizone solution would be needed if this concentration were used. A more concentrated dithizone solution (0.01%) was tried in another determination. The separations appeared to be made satisfactorily. However, it was found that a solution as concentrated as this in dithizone or in metal dithizonates would not transmit sufficient light for measurement. This difficulty was surmounted by pipetting one milliliter (one-tenth of the amount added in the case of the copper and zinc) and diluting it with clear carbon tetrachloride back to 10 ml. This brought the dithizone concentration back to .001 percent and the instrument was found to function adequately. In the case of the lead separation, 2 ml were pipetted from the 5 ml originally used and then rediluted to 5 ml for determination.

Standard curves were prepared as follows. Standard solutions of concentrations similar to those anticipated in the unknowns were made up, using accurately weighed amounts of copper sulfate, metallic zinc, and lead nitrate. These were then treated in the same way as the blank. The unknowns and the carbon tetrachloride extracts were diluted and placed in the instrument. The slide wire was moved until the galvanometer showed no deflection. The transmission readings obtained in this manner were plotted against the metal content of the standard solutions to obtain the standardization curve. Then when the unknowns were determined in the same manner, their concentrations were arrived at by referring their scale readings to the standardization curve. In actual practice the determinations were made in five groups at five different times and one or two known samples were run with each group, along with the corresponding blank.

CALCULATIONS

When the "assay" or determination of the quantity of metal in the carbon tetrachloride phase has been completed, the metal concentration in either ash or twig is easily calculated. Since all the separations in this investigation are assumed to be stoichiometric in character, the amount of metal in the carbon tetrachloride phase is the total metal content of the sample. This total amount is then divided by the weights of original ash and twig and results are reported as parts per million of each.

These data and calculations are given on the figures in parts per million (ppm) of copper, zinc, and lead for both ash and twig, although the twig value is the one most generally used. In addition, the copper-zinc ratio (for twig values) was calculated since as Warren (6) suggests, where both metals are present, this ratio may be more useful that either value alone.

RESULTS

The four sets of values—concentrations of copper, lead and zinc in twigs, as well as copper-zinc ratios—were plotted on maps of the deposit with the results shown on Figure 1 and in Table 1. Neither the copper nor the zinc data show much relation to structure, although the zinc values are well above Warren's average zinc value, which would indicate zinc mineralization. The

lead results are somewhat more promising as they seem to show an increase in average value for each lower traverse. However, much less is known about what should be expected in the case of average lead values and their variations, so that these data are probably of less value than the copper-zinc data. The plot of the copper-zinc ratios also shows no relation to the structure of the deposit, but an encouraging fact is observed: the average value

TABLE I

Sample	Wt. twig, grams	Wt. ash, Mg	% ash	ppm ash			ppm twig			Cu/Zn
				Cu	Zn	Pb	Cu	Zn	Pb	
1	8.09	81.6	1.01	318	9,200	61	3	93	.6	.03
2	1.02	11.8	1.16	280	25,400	Tr	3	294	Tr	.01
3	.99	10.7	1.08	1,570	19,600	112	17	212	1.2	.08
4	1.04	10.9	1.05	2,310	36,100	0	24	379	0	.06
5	8.04	88.8	1.10	250	8,400	56	3	93	.6	.03
6	1.00	10.7	1.07	2,350	22,800	Tr	25	244	Tr	.10
7	.93	12.7	1.37	409	18,600	Tr	6	254	Tr	.02
8	.98	18.0	1.84	244	46,600	98	4	186	.8	.02
9	1.05	9.2	0.88	3,000	22,200	120	26	194	1.0	.13
10	1.06	14.5	1.37	358	24,000	206	5	328	2.8	.02
11	1.07	9.4	0.88	224	11,700	149	2	103	1.3	.02
12	.99	9.2	0.93	2,280	24,800	97	25	231	.9	.11
13	1.11	10.3	0.93	860	44,000	87	8	408	.8	.02
14	1.00	8.6	0.86	1,040	21,000	116	9	180	.1	.05
15	.98	6.8	0.69	1,380	21,200	Tr	10	147	Tr	.07
16	6.49	68.8	1.06	298	11,100	77	3	104	.7	.03
17	.94	9.0	0.96	1,040	20,700	111	10	198	.9	.05
18	1.02	9.2	0.90	2,160	33,400	0	20	294	0	.07
19	1.00	11.5	1.15	565	27,800	Tr	7	320	Tr	.02
20	.98	9.1	0.93	0	32,300	154	0	300	1.4	.00
21	.96	12.6	1.31	666	19,500	262	9	256	3.4	.04
22	1.02	8.4	0.82	1,990	21,600	155	16	178	1.3	.09
23	.97	8.9	0.92	730	12,100	Tr	7	111	Tr	.06
24	6.78	36.3	—	954	12,400	80	± 9	±125	± .8	.07

of all 24 copper-zinc ratios is 0.05 or less, a definite indication of zinc mineralization according to Warren and Delavault. They report (6) 0.10 to be an average value, and smaller values to be indicative of mineralization in which zinc is more important than copper, as in the case here described.

SUMMARY AND CONCLUSIONS

In evaluating the method and results presented here several factors must be considered. The method itself, in the case of copper and zinc, is adapted from Warren and has been giving successful results for several years. The technique used for lead was similarly a modification of that suggested by Sandell. From the chemical viewpoint, then, it should be successful. The irregularity of the results, particularly in copper and zinc, however, might seem to make the success of these methods at best questionable. Some of the variation may be due to slight differences in the blank used on different days. This source could be reduced by analyzing all the samples at one time.

Only 24 samples were taken and analyzed, and a far larger number would obviously be preferred. The reason for this was lack of time, for the final results would undoubtedly have been more meaningful if several times this number had been assayed.

The results as they stand, however, do yield some information about the deposit that is of value. The copper-zinc ratio points to an ore high in zinc and the lead results show a suggestion at least of the outline of the ore body. Probably the best way to improve the results would be to increase the number of samples and to place them on a more tightly controlled grid. Then, more information about the structure and possibly the extent of the halo could be obtained.

Another factor that undoubtedly enters the picture is the relative solubilities of the metals in question and the effect of soil pH on these solubilities. An obvious reason for the low lead values, aside from any biological considerations, is the low solubility of lead salts. Since the solubility of copper and zinc salts may be affected by soil pH, an explanation for irregularities in their assays might be found in the extreme variability of soil in an area such as this where there are numerous, unanticipated changes of thickness, amount, and character of foreign glacial material.

The methods used in this investigation would seem, then, to have been successful, at least in furnishing a first approximation. Enough analyses are available to give an adequate but very crude reflection of the deposit. It would seem, therefore, that the main shortcoming in outlining the ore body, always a most desirable objective, is the paucity of samples taken in the present instance.

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ORE GENESIS LABORATORY,
NEW YORK CITY,
Jan. 6, 1955

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USE OF THE ANGLE PRISM IN GEOLOGIC MAPPING

W. C. PETERS

ABSTRACT

By turning a line of sight exactly 90 degrees, the angle prism provides an easily plotted relationship between survey points. It is an inexpensive hand-held instrument which requires no adjustment and may be used to advantage in many types of geologic mapping.

The instrument is particularly useful in constructing grid maps and underground stope maps. It may also be used in finding distances to inaccessible objects, in providing secondary control for plane table surveys, and in checking completed maps against gross error. A rapid triangulation net can be constructed with the prism and plotted on coordinate paper.

THE angle prism or "optical square" is a pocket instrument with wide application to geologic reconnaissance and to detailed mapping. It requires no adjustment and may be "read" quickly. Lines are established with a high degree of accuracy for distances within the limit of unaided vision. As a supplementary instrument to compass, plane table, or transit, the angle prism can be used on the surface or underground to establish secondary control points with attendant saving in time and increase in accuracy.

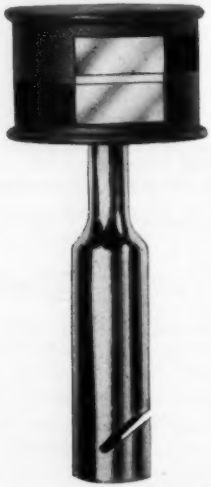
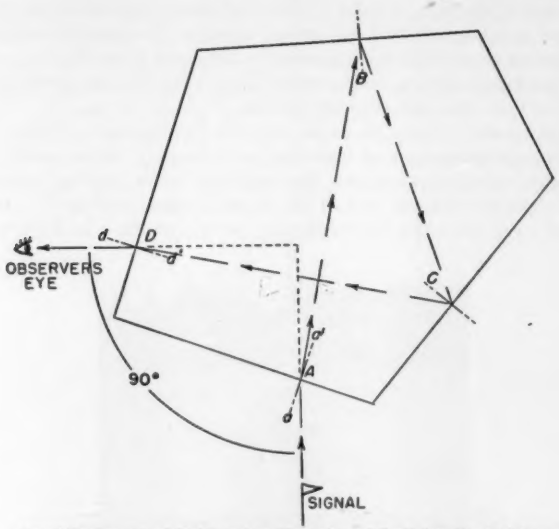


FIG. 1. Double pentagonal prism, Courtesy Keuffel and Esser Co.



An oblique ray of light enters the prism at A; it is refracted toward the normal (a–a'), is reflected at B and C, and leaves the prism at D after being refracted away from the normal (d–d').

FIG. 2.

Several types of inexpensive angle prisms are available. Triangular prisms, pentagonal prisms, and right-angle mirrors have the common property of turning a line of sight exactly 90 degrees. Each instrument makes use of the optical principle that angles of incidence and reflection are equal and lie within the same plane.

For geologic and topographic work, the best instrument is a double pentagonal prism by which lines are simultaneously established at 90 degrees to

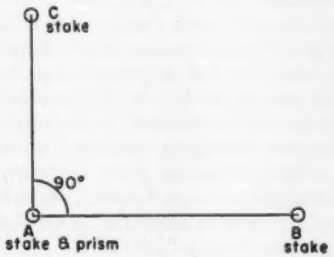


FIG. 3.

right and left of the line of sight.[1] The instrument contains two pentagonal prisms fixed in opposite directions and a "window" for the line straight ahead. The instrument is provided with a hook for attaching a plumb line. One type of double pentagonal prism is shown in Figure 1. In this particular model, the "window" lies between the two prisms.

Each pentagonal prism, by means of reflecting surfaces, rotates a line of sight 90 degrees regardless of how the instrument is turned within a plane that contains both the prism and the targets. Upon passing obliquely into the prism, light is refracted toward the normal; upon leaving the prism, light is refracted away from the normal by the same amount. In Figure 2, a ray

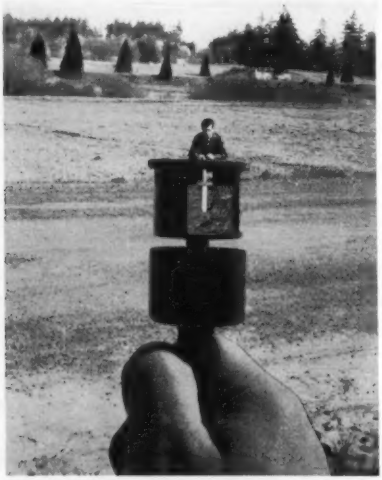


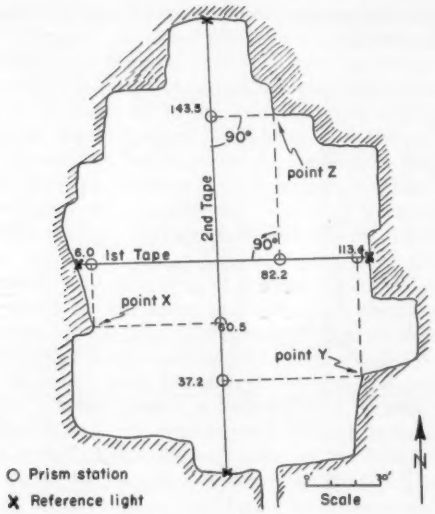
FIG. 4. Courtesy Wild Heerbrugg Instruments, Inc.

of light from a survey signal is shown passing into the prism and emerging at a 90 degree angle in spite of the fact that the ray does not strike the prism normal to the receiving face.

A typical situation in which either a single or double pentagonal prism can be used is shown in Figure 3 where stakes A and B have been established and it is desired to place stake C in line at a right angle to A-B. The observer, holding the instrument over A, finds B in the prism face. He then motions his assistant into position at C. When C is properly occupied, a stake held by the assistant will be seen through a "window" in alignment with B. The observer's view in a single pentagonal prism is shown in Figure 4; stake B is seen in the lower half of the prism and stake C, held by the assistant, is seen through the "window." It will be noted that a vertical hair is not necessary inasmuch as two signals are visually "joined."

[1] Double pentagonal prisms cost between nineteen dollars and twenty-seven dollars.

So long as all points concerned are in a roughly horizontal plane, no difficulty arises in aligning the targets within the field of the prism. If relief is slight, targets can be easily matched by moving the eye-point up or down while keeping the prism faces vertical by weight of a plumb bob or by a special staff. In areas of strong relief, the prism is not universally applicable. It does, however, perform many functions within the limits imposed by the following principle of descriptive geometry: "two perpendicular lines appear perpendicular in any view that is a normal view of either or both of the



PLAN OF STOPE SHOWING PRISM STATIONS

FIG. 5

lines, but do not appear perpendicular unless the view is a normal view of at least one of them." [2] Maps deal only with the horizontal plane; it is therefore necessary that either the reference line or its perpendicular be horizontal. This limitation is observed by first using the prism as a hand level (the prism is turned sideways to view a horizontal projection of the plumb line) and then occupying stations which permit use of a horizontal line. Targets will be foreshortened if the prism is turned sideways and will be rotated if the prism is tilted forward. Matching of targets is not difficult in either case. A refinement may be achieved by mounting the instrument on a compass tripod so that it will rotate in a vertical plane. The instrument is levelled by any small bullseye bubble. Points on the reference line and the perpen-

[2] Rowe, E. R., Engineering Descriptive Geometry, Van Nostrand, New York, 1939, p. 41.

dicular point may then be established at different levels by first effecting a horizontal projection of one of the lines.

As with any surveying instrument, practice is required for efficient operation. The actual working error is generally small and is a function of the observer's vision rather than of the instrument itself. A field check can be made by establishing a prism station over a point on a reference line and then establishing a perpendicular stake at unit distance by separate use of each prismatic view. If the two stakes do not coincide, the working error is apparent. The writer's field error, established in this manner for gently rolling country, is about two minutes as opposed to one and one-half degrees for Brunton compass work.

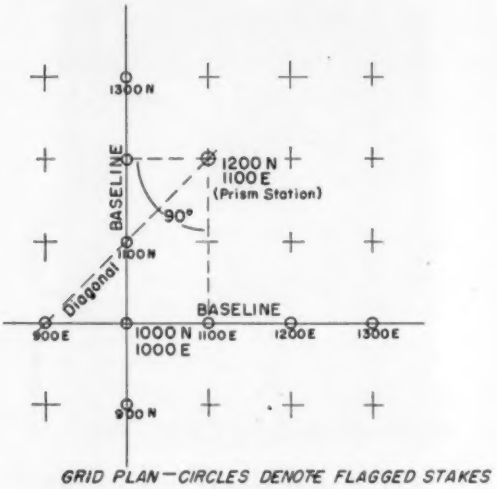


FIG. 6.

Application of the instrument is somewhat limited in brushy areas because the line of sight is fixed and may not be adjusted to avoid obstructions without occupying extra stations. It will be found that there are blind spots on some hill tops and in some canyons where the prism cannot be brought into line with all targets unless alignment stakes are established.

Common field uses for the instrument are suggested by the following examples:

1. Alignment on a baseline—the forward chainman may use the right and left prismatic views to align himself between flags at the ends of the line. Similarly, the prism may be used to place a transit tripod exactly on line.

2. Plus and offset to objects not on line—the point of offset on the main tape is accurately established with a prism and the distance measured with a second tape. In stope surveys this practice is especially useful in that refer-

ence lights at the ends of the main tape can be easily aligned in the prism faces while the offset light, held by an assistant, can be found in the "window." If two tapes are established at right angles on the bottom of a stope, it is not necessary to measure the offset distance. The position of offset may be read on each tape as shown in Figure 5. In this illustration, point x is found by establishing a normal line from the first tape at 6.0 and from the second tape at 60.5. Points y and z and as many additional control points as are needed can similarly be found by reference to the two tapes.

3. Plotting detailed geology or making a scintillometer survey within a grid—in this case two baselines are established at a right angle through the center of the area. Flagged stakes are placed at regular intervals. The position of any grid point within the area may be determined at the time the point is occupied as shown in Figure 6. It should be noted that a simple right angle will not definitely fix a point within the grid; diagonal alignment must also be made through other baseline stakes by sighting past a plumb line.

4. Distance to inaccessible features—for reconnaissance purposes, distance may be determined without reference to trigonometric tables by use of the prism and two short baselines. In Figure 7, a method is shown in which two sides of a small right triangle are measured and the relationship thus found applied to a larger similar triangle which includes one of the known sides. In this case, the first flag is established at any convenient point. The second flag is established by use of the prism so that lines to the inaccessible object and the first flag form a right angle. The third flag is established by use of the prism so that a right triangle is completed. Sides a and b are then taped and the distance to the inaccessible feature calculated as indicated in the figure. The dotted left-hand triangle with a fourth flag may be used as a check on the distance thus determined. In applying this method in the field, the writer has not taken time to find completely level areas for the base triangle; in spite of this basic inaccuracy, the calculated distance has always fallen within eight percent of the actual distance when later found by conventional methods.

5. Secondary control shots in "blind" areas—the rodman may in this case provide extra detail which is not visible to the instrument man (Fig. 8). At a convenient station the rodman notes a prominent feature which lies at a right angle to the line from the instrument. He then occupies another rod station which will furnish an additional right angle between the lines to the instrument and to the feature. The feature is then located as shown in Figure 7. A third station would be occupied if a three-line intersection is warranted.

6. As a check against gross error in a completed plane table sheet—certain groups of features can generally be found to bear a 90-180-270 degree relationship to points on the map. Upon occupying the point chosen, the relationship can be quickly verified in the field. A few hours spent with a prism at the close of a geologic mapping program may keep embarrassing discrepancies from becoming apparent at a later date in "sketched-in" areas.

7. Reconnaissance triangulation—in cases where a triangulation net would be helpful but time does not permit transit or plane table work, the prism may be used to advantage by a single geologist. A prism-derived net, as shown in Figure 9, uses squares and quadrilaterals and can be drawn rapidly on co-

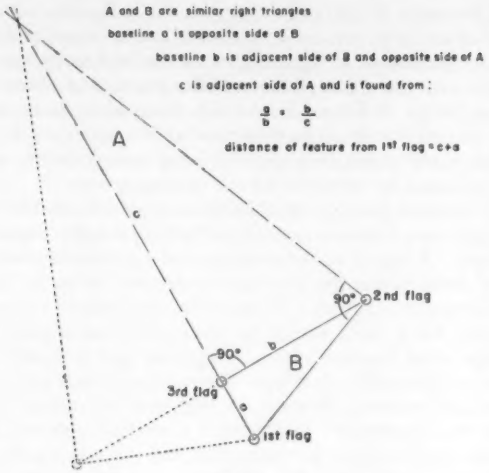


FIG. 7.

ordinate paper. Two baselines are established at a right angle and distances measured as dictated by the size of the squares and by the terrain. As in the example regarding grid work, positions are not established by a single right angle; use must be made of diagonals wherever possible. If adjacent flags

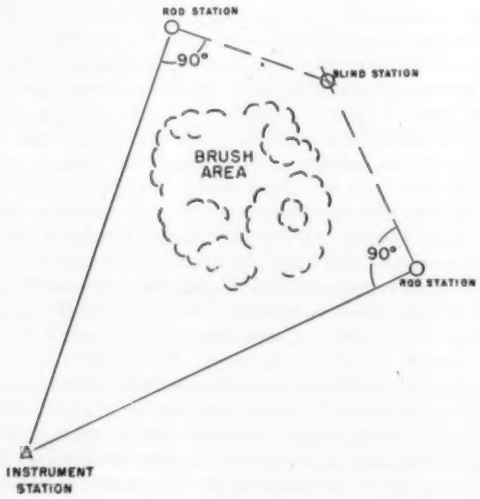


FIG. 8.

are not visible, alignment is provided by sighting along a plumb line at two or more flags in any direction. Such a net requires relatively open country and subdued topography. However, once the net is established it may be deflected occasionally in areas of brush or of difficult terrain. Elevation control is added by altimeter or by using the prism turned on its side as a hand level.

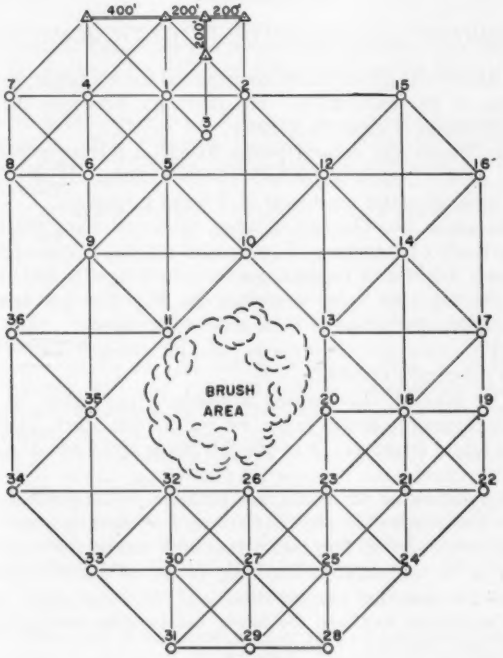


FIG. 9.

Additional uses will become apparent in the field. The angle prism most commonly serves as a reconnaissance instrument which adds considerable accuracy to compass sketches but yet is not as bulky and time consuming as a plane table or transit.

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Jan. 6, 1955

DISCUSSION

THE GENESIS OF ASBESTOS IN ULTRABASIC ROCKS

Sir: Mr. Riordon is greatly to be commended for his paper in the January-February issue of this publication. He offers the first new theory in many years on the problem of asbestos genesis.

The writer would add several points based on former experience at the Jeffrey Mine of the Canadian Johns-Manville Company Ltd. This mine is at Asbestos, some 40 miles southwest of Thetford, Quebec.

First—Numerous two-fibre veins, when separated along the median parting, reveal a botryoidal surface of low relief on the thicker portion. This feature supports the idea of formation as a colloidal gel in fractures.

Second—the serrated veins described by Riordon are fairly common, forming a considerable portion of some small rock masses. Some of this fibre is long enough to tease up with a needle, and its strength and flexibility leave little doubt it is actually chrysotile.

Third—The kinking that causes a banded appearance in many wide asbestos veins commonly angles from one wall to the other. In some places it also grades into a fracture. It is possible these kinks are due to post-fibre movement.

Fourth—Gradation of chrysotile into picrolite is not general at Asbestos, and it may be that much chrysotile has crystallized directly from a gel.

It may be commented in conclusion that high temperatures have not been demonstrated to be the major controlling factor in asbestos genesis. This writer favours the view that granitic dikes and chrysotile occur in proximity, not because the former localized the latter, but because emplacement of both was controlled by "solution" channelways.

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April 1, 1955

REVIEWS

Conserving Natural Resources—Principles and Practice in a Democracy. By SHIRLEY W. ALLEN. Pp. 347; figs. 168. McGraw-Hill Book Co., New York, 1955. Price, $5.50.

This is written for a textbook. It covers the entire field of natural resources, including minerals. The author is Professor Emeritus of the Department of Forestry, University of Michigan, and is also the author of An Introduction to American Forestry.

In this book the author discusses the nature of each group of resources and its significance in the individual and national economy. He treats of the practices that lead to depletion and those that lead to conservation. He gives attention to human power, smog, and transportation. There are only 7 chapters, namely: Introduction; The Land, Soil, and Conservation; Water; Forests, Grazing, and Recreation; Wild Animal Resources; Mineral Resources; and Human Powers as Natural Resources.

Under Mineral Resources, the author devotes a page or so to national and state mineral policy, and then takes up mineral fuels, giving brief sketches of history, origin and occurrence, ranks, distribution, waste, ownership, conservation, and future outlook for coal resources. Petroleum and natural gas are similarly treated. Iron is given generally similar treatment with conservation stressed. Some of the chief metals and non-metallic minerals are considered from the standpoint of ownership and conservation, for which the author leans heavily on the President's Materials Policy Commission report, "Resources for Freedom."

The book is well balanced, nicely written, and must be considered among the best, if not the best, book dealing with the subject of conservation of natural resources.

Géologie des Barrages, et des Aménagements Hydrauliques (Geology of Damsites). By M. GIGNOUX and R. BARBIER. Pp. 343; pls. 28; figs. 176. Masson et Cie, Paris, 1955.

This authoritative book, with its excellent illustrations, covers broadly the field and problems of dam construction. Of its six chapters, the first four deal largely with geological features. Chapter 1 takes up land forms, particularly stream valleys, glacial valleys and various types of lakes. Chapter 2 deals with unconsolidated deposits such as residual and transported soils and glacial deposits. Chapter 3 considers movements of surficial deposits. The following chapter goes into the geologic problems of dam foundations on different types of soils and bed rocks, problems of water retention behind dams, and of the materials available for construction of large dams. The following chapters deal with the construction of dams, underground water, tunneling as affected by different kinds of rocks, drilling, grouting, tools and equipment.

The text matter is abundantly and finely illustrated with beautiful photos of foundation sites, dams and reservoirs, maps of watersheds, and drawings of land

forms in relation to foundations and reservoirs. The fine illustrations are widely drawn from Europe and French Africa.

The coverage is very complete and it is the best book on this subject known to the reviewer. It is also a fine piece of book-making, with a striking black cover titled in gold and red. The authors and publisher are to be congratulated in bringing forth this fine reference book.

Textures of the Ore Minerals and Their Significance. By A. B. EDWARDS. Pp. 242; figs. 204. Australasian Inst. of Mining and Metal., Melbourne, 1954.

The first edition of Dr. Edwards' book immediately won worldwide recognition and distinction. This second edition is therefore welcome, inasmuch as it brings up to date the information that has accumulated since then, such, for example, as Bastin's book on the Interpretation of Ore Textures and Ramdohr's excellent book, in addition to much other new information. The same general form has been followed as in the first edition, but all new information that the author has been able to find has been included in this new edition. This edition, as did its predecessor, carries beautiful illustrations of the different types of textures encountered in the examination of ores. The book should continue to serve even better than its predecessor. It is an excellent general reference for all students of ore textures.

Some Fundamentals of Petroleum Geology. By G. D. HOBSON. Pp. 139; figs. 41. Oxford University Press, London, 1954. Price, $2.90.

This little book is a very brief introduction to petroleum geology by an author who is lecturer in Oil Technology on the staff of the Geology Department of the Imperial College of Science and Technology. Its five chapters deal, respectively, with the Nature of an Oil Accumulation, Reservoir Fluids, Origin of Petroleum, Migration and Accumulation, and Reservoir Pressure. Three Appendices deal briefly with Compaction, Definitions, and an Addendum of late information. The essentials of petroleum geology are covered, although in very brief manner. It is well written in understandable language to an elementary student.

Die Eigenschaften der Minerale. By ARNO SCHÜLLER. Pp. 602; figs. 49. Akademie-Verlag, Berlin, 1954. Price, DM 42.

Part A, introductory (39 pp.) gives the general properties and constitution of minerals, with phase diagrams, reagents, reactions, tables of properties, atomic numbers, weights, isotopes, and atomic radii. The main part of the book is composed of mineral tables according to the elements and mineral groups, giving for each mineral, in abbreviated form, the chief properties and mode of formation. This is followed by 27 pages of "Systematische Übersicht" giving class, element and metal.

Journal of the Geological Society of Australia, Volume 1, for the year 1953. Pp. 133. Adelaide, 1954. Price £2 2 0.

A new geological journal has made its appearance from the distant continent of the Southern Hemisphere, and provides a new outlet for publication of geological studies of the region. The editor is M. F. Glaessner, and editorial advisors are W. R. Browne, E. S. Hills, and A. A. Öpik. Its debut is made with 5 articles, as follows: A. B. Edwards and G. Baker, Scapolitization in the Cloncurry District of

north-western Queensland; R. O. Brunnschweiler, Mesozoic stratigraphy and history of the Canning Desert and Fitzroy Valley, Western Australia; E. den Tex, Stereographic distinction of linear and planar structures from apparent lineations in random exposure planes; S. Warren Carey, The Rheid concept in geotectonics; E. Sherbon Hills and D. E. Thomas, Turbidity currents and the graptolitic facies in Victoria.

Our best wishes go to the new journal and may it long continue to publish meritorious articles.

Hugh Roy Cullen—A Story of American Opportunity. By ED KILMAN and THEON WRIGHT. Pp. 376; Ill. Prentice-Hall, Inc., New York, 1954. Price, $4.00.

This is the story of the fabulously rich "King of Texas Wildcatters," an oil pioneer who became one of America's wealthiest men and one of the greatest of philanthropists. He established the Cullen Foundation, to which he has given more than $100,000,000, and this foundation largely built the University of Houston. There are also other large philanthropic donations for educational, medical, religious and other social benefits.

The book tells of his life, and of his early difficult problems of drilling for oil, and of his later successes. It is a story of opportunity in America for a poor boy, and of what lay back of some of the great decisions he had to make. It is a story that geologists in particular will enjoy.

BOOKS RECEIVED

U. S. Geological Survey—Washington, D. C., 1954.

Prof. Paper 260-I. Recent Corals of the Marshall Islands. Bikini and Nearby Atolls, Part 2, Oceanography (Biologic). J. W. WELLS. Pp. 385–486; pls. 94; figs. 4; tbls. 4. Price $5.50. *Ecologic and taxonomic analysis of living reef- and non-reef-building corals at Bikini and other Marshall Islands atolls.*

Prof. Paper 267-A. Geology of the Brandywine Area and Origin of the Upland of Southern Maryland. JOHN T. HACK. Pp. 43; pls. 2; figs. 34. Price $1.50. *Detailed study of geologic history and origin of surficial deposits of small area on Coastal Plain.*

Prof. Paper 267-B. Hardpan Soils of the Coastal Plain of Southern Maryland. C. C. NIKIFOROFF. Pp. 45–63; fig. 1; tbls. 2. Price 15 cts. *Reconstruction of environment in which soil formation took place.*

Prof. Paper 271. The Natural Channel of Brandywine Creek, Pennsylvania. M. G. WOLMAN. Pp. 56; figs. 39; tbls. 5. Price 55 cts.

Bull. 989-G. Geology and Coal Deposits, Jarvis Creek Coal Field, Alaska. CLYDE WAHRHAFTIG and C. A. HICKCOX. Pp. 353–367; pls. 3; fig. 1; tbls. 2. Price 65 cts. *Stratigraphic study of coal field and estimate of reserves.*

Bull. 999. Annotated Bibliography of the Bauxite Deposits of the World. ELIZABETH FISCHER. Pp. 221; pl. 1. *Includes papers through December, 1950.*

Bull. 1011. Pegmatites of the Crystal Mountain District, Larimer County, Colorado. WILLIAM THURSTON. Pp. 185; pls. 13; figs. 32; tbls. 16.

Bull. 1012-A, B. Fluorspar Deposits in Western Kentucky. Part 1. Pp. 37; pls. 4; figs. 1. Price $1.00. *Includes: A. Introduction, by J. S. Williams and Helen Duncan; B. Babb fault system, Crittenden and Livingston Counties, by G. C. Hardin, Jr.*

Bull. 1022-D. Geophysical Abstracts 159, October–December, 1954. MARY RABBITT, DOROTHY VITALIANO, S. T. VESSELOWSKY, and others. Pp. 205–319. Price 25 cts.

Water-Sup. Pap. 1230. Ground-Water Conditions in the Rincon and Mesilla Valleys and Adjacent Areas in New Mexico. C. S. CONOVER. Pp. 200; pls. 9; figs. 15; tbls. 13. Price $1.50.

Water-Sup. Pap. 1260-A. Floods of September 1952 in the Colorado and Guadalupe River Basins, Central Texas. S. D. BREEDING and J. H. MONTGOMERY. Pp. 47; pl. 1; figs. 10; tbls. 2. Price 45 cts.

Water-Sup. Pap. 1260-B. Floods of April 1952 in the Missouri River Basin. Prepared under the direction of J. V. B. WELLS. Pp. 49–302; pls. 3; figs. 37; tbls. 12.

Calif. Div. of Mines, San Francisco.

Calif. Journal of Mines and Geology, Vol. 50, Nos. 3 and 4, July–Oct., 1954. Pp. 439–780; pls. 5; figs. 52. Price $2.00. *Contains: The Cool-Cave Valley Limestone Deposits, El Dorado and Placer Counties, California, by William B. Clark; Mines and Mineral Deposits of Los Angeles County, California, by T. E. Gay, Jr. and S. R. Hoffman; Annual Report of the State Mineralogist, Chief of the Division of Mines, for the 105th Fiscal Year, by Olaf P. Jenkins.*

Calif. Journal of Mines and Geology, Vol. 51, No. 1, January, 1955. Pp. 95; pl. 1; figs. 26. Price $1.00. *Includes: Mineral Use in Coated Welding Electrodes, by Richard M. Stewart; and Mines and Mineral Resources of San Joaquin County, California, by W. B. Clark.*

Quarterly of the Colorado School of Mines, Golden.

Vol. 49, No. 4, Oct., 1954. Study of Physical Properties in the Refining of Petroleum. G. W. LEMAIRE. Pp. 87; figs. 41; tbls. 27. Price $2.50.

Vol. 50, No. 1, Jan., 1955. Classification of Rocks. R. B. TRAVIS. Pp. 98; pls. 66; figs. 4. Price $1.00. *Summarized petrographic classification of igneous, sedimentary and metamorphic rocks.*

Illinois Geological Survey, Urbana. 1955.

Rept. 177. Illinois Mineral Industry in 1953. WALTER H. VOSKUIL. Pp. 42; figs. 11; tbls. 33.

Rept. 178. Metamorphism of Coal by Peridotite Dikes in Southern Illinois. K. E. CLEGG. Pp. 18; pl. 1; figs. 4.

List of Publications on Illinois Geology, Mineral Resources, and Mineral Industries, List of Published Maps, and Index to List of Publications by Subject, by County, and by Author. Pp. 165.

Indiana Geological Survey, Bloomington. 1954.

Circ. 3. Common Rocks, Minerals, and Fossils Found in Indiana. N. M. SMITH, A. C. BROOKLEY, JR., and D. J. MCGREGOR. Pp. 24; figs. 6.

Rept. of Progress 8. Gypsum and Anhydrite Deposits in Southwestern Indiana. D. J. McGregor. Pp. 24; pls. 2; figs. 2. Price 50 cts.

Chemical, Petrographic, and Ceramic Properties of Four Clays from the Dakota Formation in Kansas. Norman Plummer et al. Pp. 157–216; pls. 3; figs. 17; tbls. 17. Bull. 109, Part 10. Kansas Geological Survey, Lawrence, 1954.

Investigation of Lightweight Aggregate Possibilities of Some North Dakota Clays and Shales. Oscar E. Manz. Pp. 48; figs. 3. Rept. 17. North Dakota Geological Survey, Grand Forks, 1954.

Oil and Gas in Morgan County. B. D. Magbee and R. L. Alkire. Pp. 69; pls. 5; figs. 24. Rept. 22. Ohio Geological Survey, Columbus, 1954. Price $1.00. *Review of history and development of the oil and gas industry in Morgan County.*

Oil and Gas Exploration in Oregon. R. E. Stewart. Pp. 53; figs. 3. Misc. Pap. No. 6. Oregon Dept. of Geology and Mineral Industries, Portland, 1954. Price $1.00.

Progress Report on Selected Ground-Water Basins in Utah. Pp. 128; figs. 29; tbls. 13. Technical Pub. No. 9. U. S. Dept. of the Interior, 1954. *Includes: Status of Ground-Water Development in Four Irrigation Districts in Southwestern Utah, by H. A. Waite et al.; Pumping Costs in Southwestern Utah, by W. B. Nelson; Ground-Water Possibilities of Bedrock Aquifiers in Southeastern Utah, by B. E. Lofgren; Investigation of Geology and Occurrence of Ground-Water in the Weber Basin Project Area, Farmington to Willard, Utah: A Progress Report, by J. H. Feth.*

Branssat-Daine Area, Abitibi-East County. J. E. Gilbert. Pp. 42; pls. 9. Geological Rept. 64. Quebec Dept. of Mines, Quebec. 1955.

XIX Congrès Géologique International, Faculté des Sciences, Alger, Algérie. 1953–1954.

Comptes Rendus de la Dix-Neuvième Session, Alger, 1952.

Fascicule XII. Questions Diverses de Géologie Appliquée. Pp. 373. *25 papers or abstracts in English, French or German on various subjects related to applied geology. Includes papers on geochemistry and structure as related to mineral deposits.*

Fascicule IX. Contribution de la Géophysique a la Géologie. Pp. 376. *31 papers or abstracts in English, French, German and Spanish on contributions of geophysics to geology.Includes papers on gravity, magnetic and seismic studies.*

Fascicule V. Questions Diverses de Géologie Générale, Troisième Partie, Paléontologie Stratigraphique, Quaternaire et Pétrographie. Pp. 595. *66 papers and abstracts, English, French, German and Russian on stratigraphic paleontology, Plio-Pleistocene boundary, Pleistocene features and petrography.*

Fascicule XVI. Les Champs de Pétrole des Régions Mésogéennes. Pp. 299. *21 papers in French and English on oil fields in Mexico, Brazil, Middle East, Caribbean Sea and North Africa. Emphasis on areas bordering Tethyan geosyncline.*

Fascicule XVII. La Paléovolcanologie et ses Rapports Avec la Tectonique. Pp. 239. *23 papers and abstracts in English, French, German or Spanish on paleovolcanology and its relationships to tectonics.*

Fascicule XX. Association des Services Géologiques Africains: Première Partie, Général, Précambrien et Primaire Ancien. Pp. 362. *32 papers and*

abstracts in French and English on general, Precambrian and Early Paleozoic subjects in Africa.

Fascicule XXI. Association des Services Géologiques Africains: Deuxième Partie, Questions Diverses et Annexes. Pp. 430. *40 papers and abstracts in French or English on African subjects. Includes 10 papers on Karoo and Kolahari; 8 on Nubian sandstones, Mesozoic, and Cenezoic; 4 papers on laterites; 10 papers on Tunisia and Algeria.*

Les Schistes Cristallins des Massifs du Grand Paradis et de Sesia-Lanzo (Alpes Franco-Italiennes). ROBERT MICHEL. Pp. 290; figs. 51; tbls. 4. Sciences de la Terre, Tome 1, 1953, Numeros 3–4. Ecole Nationale supérieure de Géologie, Nancy, 1953. *Detailed petrographic, mineralogic, chemical study of crystalline rocks of Pennine zone of western Alps. Chemical and mineralogical changes in course of metamorphism; observations on polymetamorphism and diapthoresis. General discussion of soda metasomatism.*

Mineral- und Erzlagerstättenkunde. H. HUTTENLOCHER. Pp. 118; figs. 36. Walter de Gruyter and Co., Berlin, 1954.

Revista de Hidrocarburos y Minas. Pp. 155. Año V–Núm. 16, Julio–Setiembre, 1954. Venezuela Ministerio de Minas e Hidrocarburos.

SCIENTIFIC NOTES AND NEWS

ALVIN W. KNOERR has been appointed editor of *Engineering & Mining Journal and E & M J Metal & Mineral Markets* effective Feb. 15. He is succeeding ROBERT H. RAMSEY, who has resigned to join the staff of the St. Joseph Lead Company in New York.

D. P. KING has left Anaconda Mining Company, at Butte, to join the Atomic Energy Commission's Raw Materials Division, Denver Exploration Branch in Denver, Colo.

ROBERT J. WRIGHT has resigned as Chief, Geologic Branch, Atomic Energy Commission, Grand Junction, Colo., to join the exploration staff of Climax Uranium Company, also of Grand Junction.

The Pan-Malaya Scientific Advisory Council has set up a technical committee on mineral resources to assist Malaya's mining industry.

FRANK PRESS has been appointed professor of geophysics in the Division of the Geological Sciences at the California Institute of Technology. Now associate professor of geophysics at Columbia University, Dr. Press expects to join the group working at Caltech's Seismological Laboratory by mid-September of 1955.

WILLIAM J. SHEDWICK, JR., Consulting Mining Engineer of Mexico City, is currently in Quito, Ecuador, making geologic studies in connection with a hydraulic installation under contract to John J. Harte Company of Atlanta, Georgia, financed by the Export-Import Bank of the United States and The International Bank for Reconstruction and Development in Washington.

JACK W. REINHART, formerly with American Smelting and Refining Company, became the Manager of the Geology and Quarry Operations Department, Great Lakes Carbon Corporation, Perlite and Dicalite Divisions, Los Angeles, California, on March 1, 1955.

PAUL V. SMITH, JR., Esso Research and Engineering Company, Linden, New Jersey, was chosen to receive the President's Award at the American Association of Petroleum Geologists' annual convention in New York City, March 29. This award consists of a certificate and $100 in cash and is given annually to the author under 35 years of age whose article in the Association *Bulletin* of the preceding year is judged by the Medal Award Committee to be the most significant original contribution to petroleum geology. The winning paper this year is entitled "Studies on Origin of Petroleum: Occurrence of Hydrocarbons in Recent Sediments," published in the March *Bulletin*.

JOHN E. FROST has left American Smelting and Refining Co., Salt Lake City, to accept the position of chief geologist, Philippine Iron Mines, Inc., Philippine Islands.

W. H. WHITE of the Department of Geology, University of British Columbia, has been elected chairman of the British Columbia Section, Canadian Institute of Mining and Metallurgy.

ROLAND D. PARKS, Assoc. Prof. of Mineral Industry, Massachusetts Institute of Technology, is on a year's leave of absence as guest professor at the Indian School of Mines and Applied Geology, Dhanbad, Bikar, India, sponsored by U. S. Foreign Operations Administration.

KEITH MARTIN is now assistant geologist for the Bear Creek Mining Co., Tucson, Arizona. For the past two years he was geologist with Chino Mines Div., Kennecott Copper Corp., New York.

PHILIP J. SHENON, Salt Lake City geologist and former head of the mining department of the University of Utah, was chosen by Stanford University to give a series of lectures on mineral exploration. This was in accordance with the university's custom of inviting outstanding specialists to lecture in the fields of mining, geology, and metallurgy.

LOUIS GENCE is now assistant geologist, Service Geologique de Madagascar, Tananarvie, Madagascar. For the past five years he has been mine superintendent, Ste de Minerais de la Grande Ile, Fort Dauphin, Madagascar. From June to November in 1954 Mr. Gence prospected for thorianite deposits northwest of Fort Dauphin.

CHARLES E. MELBYE is now a partner in Minerals Exploration Research Corp., consultants in mining geology and geophysics, with offices at 2120 Ford St., Golden, Colo.

WAYNE O. MACKENZIE, geologist with the American Metal Co. Ltd., has been transferred from Newcastle, N. B., to Ellsworth, Me.

C. T. POTGIETER, mine geologist with Mufulira Copper Mines, Ltd., has left the Northern Rhodesian mining firm to accept a position with Union Corporation on the Rand.

HERBERT E. HAWKES of the Department of Geology and Geophysics at M.I.T. recently returned from Trondheim, Norway, where he gave a series of lectures on geochemical methods of mineral exploration at the Norwegian Technical University.

CONSOLIDATED RANWICK URANIUM MINES LIMITED, a Canadian Corporation and an associate of the Ventures Limited group, has announced the opening of offices in the First National Bank Building in Denver, Colorado. General mineral exploration, particularly for uranium ores, will be conducted by the Denver office staff. Mr. THOMAS W. MITCHAM, Exploration Manager, will head this effort from Denver. The home office of Consolidated Ranwick is in Toronto, Canada, but the management of the Company affairs is handled out of the New York office, 230 Park Avenue, New York 17, New York.

MILTON GENES has accepted the position of Geologist in the Department of Mining and Geology, U. S. Vanadium Company, a division of Union Carbide and Carbon Corp. at Uravan, Colorado.

The GEOLOGICAL SOCIETY OF AMERICA published the following article in the March, 1955, issue of its *Bulletin:* "Bibliography and Index of Literature on Uranium and Thorium and Radioactive Occurrences in the United States. Part 4: Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota and Texas," by MARGARET COOPER for the Division of Raw Materials, U. S. Atomic Energy Commission. Since this 70-page bibliography may prove helpful to both geologists and laymen interested in uranium prospecting, the Society has prepared reprints for public sale at 50 cents per copy. Remittance must accompany orders, which should be sent to: The Geological Society of America, 419 West 117 Street, New York 27, New York.

SPENCER S. SHANNON of Bedford, Pa., was sworn in as Director of the Office of Minerals Mobilization, Department of the Interior, on May 4, in the office of Secretary Douglas McKay. Mr. Shannon has served as a consultant to Assistant Secretary for Mineral Resources Felix E. Wormser since January 5, 1955. Secretary McKay announced the establishment of the Office of Minerals Mobilization on January 14, 1955. The office will carry out functions authorized by the Defense Production Act of 1950 and delegated to Secretary McKay with respect to strategic and critical metals and minerals, including solid fuels.